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CURRENT DEVELOPMENTS IN ROCK, ROCK PRODUCTS, AND INDUSTRIAL MINERALS

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* The paper, "Decolorization of Southern Illinois Silica," by J. S. Machin and F. V. Tooley, has been published since the Conference as Report of Investigations No. 47 of the State Geological Survey.

The manuscript on "Use of Geophysical Apparatus in the Prospecting of Industrial Mineral Deposits," by H. A. Buehler, State Geologist, Missouri Geological Survey, Rolla, was not submitted for publication.

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CURRENT DEVELOPMENTS IN ROCK AND ROCK PRODUCTS

PRODUCTION AND POSSIBILITIES FOR LIME- STONE RUBBLE AND ASHLAR FOR CONSTRUCTION

By

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President, Lehigh Stone Company, Kankakee

There is nothing new under the sun, but from time to time there are changes in the ways that the old materials are used.

As stone is one of the very oldest of building materials, the world is full of massive stone structures that have endured for centuries. However, such structures are not popular today, so we may well ask ourselves whether rubble and ashlar have a present and a future.

There was a time when the builder assembled his materials in the vicinity of the site of the building. If stone abounded, he built of stone; if trees were plentiful, he built of timber; if both were hard to get and clay was available, he learned to build of brick.

The general purpose of the builder was to construct a substantial shelter. Very rarely the builder had that artistic sense which demanded that a structure must be pleasing to the eye, as well as serviceable.

Consequently, as stone is a very durable material, we have plenty of old stone buildings which are everything except beautiful. On the other hand, the occasional structure with truly beautiful lines, pleases all who behold it, although few of us can explain just why we like it.

When the builder began to buy his materials, transportation became an important element in their cost, and is more important today than ever before.

Transportation brought about competition between stone, lumber and brick, and made many changes in the methods of using those materials.

Today our lumber comes from the South and the extreme West; brick plants are to be found almost anywhere, and stone, suitable for building is found in small and rather widely separated areas.

When the world discovered that air spaces in the walls of our homes add to health and comfort, the old 16-inch stone wall houses became antiques.

Wooden structures are now mostly air space and thin sheets of $\frac{3}{4}$ -inch lumber; brick has been hollowed out into modern building tile; thereby reducing transportation costs per cubic foot of building to such an extent that solid stone buildings are no longer constructed, even in those areas where good stone is plentiful.

Forty years ago, the foundation of every northern home was of brick or heavy rubble stone masonry. The perfection of portland cement in this country pushed the rubble foundation into the discard, and substituted concrete made of crushed stone or gravel.

Before the advent of concrete and structural steel, Chicago and other large cities used large quantities of rubble stone, and heavy slabs of sawed limestone. Chicago had brick in its own back yard, but depended largely upon the Joliet area for its supply of stone. Joliet tried to overcome its transportation handicap by sawing very thin slabs of stone, which were set on edge to face buildings. A few of those atrocities may be seen today in parts of Chicago's tenement district. Then the Bedford, Indiana, stone industry became active, and its cheaper cutting costs pushed Joliet sawed stone entirely out of existence.

Bedford's cheaper cutting costs and a better control of the sizes into which blocks were cut, enabled them to overcome a very great transportation handicap, and Bedford stone became a strenuous competitor of fine face brick in all classes of public buildings and even in small residences. All other types of rubble and ashlar were crowded out by materials that would make thinner walls, weighing much less per square foot of surface.

With the depression came a strange revival of rubble stone as a facing for buildings. Credit for this revival probably must be shared between the architect and the stone producer who was willing to try anything that might add a dollar to his microscopic income.

The architect had to exert himself as he had never done before, to find something that would appeal to the few owners who might be coaxed into letting a building contract. He must find something so pleasing in form, line and color, that the owner could not resist the appeal of beauty, and yet had to hold the cost down to a reasonable figure.

A stone house creates the pleasing impression of durability, but it must be modern in every other respect. Form, line and color must be given the most careful attention if the building is to be attractive, and transportation cost must approximate the transportation cost of brick.

Furthermore, the owner must feel that there is a touch of individuality to his home that is not shared in many other homes. This quest for individuality has resulted in some wierd specimens that must haunt the owner as long as he lives. So the architect must avoid extravagant innovations of that type.

One of the outstanding errors of old stone buildings is that short chunky stones were often used because longer stones were so much heavier to handle. Short stones in a wall lack the appearance of stability. They may be thoroughly bonded together, but the spectator does not get that satisfied sense of stability, unless individual stones are generally two or three times as long as they are high.

Rubble veneer, 4 inches thick, not more than 6 to 8 inches high, with lengths more than twice their heights, provides the form and the line that the architect must have to please his client, and at the same time such stones can be set in the wall by brick masons, at a cost not greatly different from the cost of setting brick.

Color is the last and possibly the most important detail that must be considered. We are all color conscious, but very few of us realize that one color scheme irritates us and another pleases us nor why we are so influenced. There is a sky-blue granite courthouse in South Carolina, which is the pride of the community. Whenever I have a nightmare, that sky blue courthouse is generally somewhere in the wierd picture. We don't expect the exteriors of our buildings to be blue, so we must make them of colors and tones that the spectator accepts as reasonable colors, if we are to produce the pleasing result.

The uniform warm buff color of Bedford stone is one of its outstanding assets in the construction of formal structures such as post offices and public buildings, because it has life and cheerfulness. Many limestones and dolomites in the Mississippi Valley offer a variety of warm tan colors that gave the architect just what is needed to convince the owner that the architect's plans for a home or a church were just what the owner wanted.

Color is of great importance. The owner with a keen appreciation of color is not satisfied with Wisconsin limestone, Ohio sandstone or Indiana limestone, because none of these competitive materials offer dense durable stone having the combination of color variety, that makes northern Illinois limestone so attractive to the architect and owner.

So it only remained for the architect to find a large enough supply of rubble veneer to insure plenty of competition and a cheap workable product.

The thin-bedded limestones of southern Wisconsin and northern Illinois afforded ideal working material, and the depression compelled stone operators to cooperate with the architect, in producing what the architect wanted.

The production of this type of stone is subject to many restrictions. It is something of a trick to cut 4-inch veneer from rough stones that lie 8 inches on their natural bed. The stone must have a uniform grain and even then the cutter must know how to handle it. There is no opportunity for machine work and quantity production. Bars and wedges are used to break the slab free from its native bed, and hammers and chisels produce the

finished product. One hundred per cent hand labor makes a production cost that staggers any one who produces crushed stone or gravel.

Windows, door openings and corners present another cutting problem because two faces must be finished on such stones. Finally fancy arches or fireplaces fall into a class of work where costs pile up above the most extravagant estimates.

The cost of breaking stones at the source of supply is much less than the same operation at the job. The main advantage is that there is much better chance to select the most desirable material as to color and size. Other savings accrue from being able to use the spalls and chips in other processes and from the fact that transportation charges are paid only on usable stone. Most ashlar are made to set on the natural bed with only enough on edge to provide contrast of color and texture. Individual stones vary in height to provide an abundance of ties and the beds and ends are clipped so that the wall joints will be moderately narrow, uniform and at right angles.

The production of this material is only the beginning of the architect's responsibility because stone masons all too often expect stone to fall into its place in the wall just as brick fall into place.



FIGURE 1.—A chapel constructed of limestone veneer on North Ashland Avenue, in Chicago. Exterior walls constructed of Lehigh rubblestone veneer and buff brick, with Bedford stone trim.

Stone must be laid carefully, with level beds, and uniform joints, and the mason must choose the individual stones with great care, if he is to give pleasing lines to his finished wall.

The possibilities for the future use of this material are rather apparent from what has just been said about its history and production. The volume

is bound to be small; when everyone has a stone house, it loses its charm of individuality. It is a luxury building material, so it will not be used when cost is the controlling factor. On the other hand, it is surprising what an insistent demand exists in certain directions for stone veneer.

It seems to be the ideal and natural material for churches built along modern lines, with steel frame and hollow tile wall backing.

The Lehigh Stone Company has been making rubble veneer for nearly four years. There has been little or no profit in its production, but we do have a rather keen satisfaction in the knowledge that many delightful gems of architecture exist as the result of efforts we have made in this field (fig. 1).

When this material is appreciated, transportation ceases to be a serious handicap. Chicago is our natural market, but Detroit, Indianapolis, Fort Wayne, East St. Louis, Rockford and Sterling proved to be within easy reach of customers who wanted Lehigh rubble veneer.

Architects, builders and owners are beginning to realize that they can combine beauty, economy and good construction by using Illinois limestone for veneering exterior walls.

Under such conditions, who can really attempt to measure its possibilities?

CURRENT RESEARCHES ON ILLINOIS STONE AND THEIR RELATION TO DEVELOPMENTS IN THE STONE INDUSTRY

BY

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INTRODUCTION

As is evident from the title, this paper naturally divides itself into two parts, first, what are the broader developments affecting the Illinois stone industry, and second, how is the Survey's research program related to these developments? With reference to the first item, it is proposed to limit discussion to matters relating to raw materials and their uses.

DEVELOPMENTS IN THE STONE INDUSTRY

Probably one of the most important developments of the last decade is the increase in consumer research which has as its objectives the discovery of sources of materials which are as good as the materials in use but cheaper, or the discovery of better materials to be had at the same price. Here arises at once the producer's boggy of cheaper substitutes which may replace his product, though substitution may have a happier turn if by reason of it instead of losing a customer a producer gains one. Without doubt, consumer research is here to stay and with ample financial backing.

Consumer research, and equally also the general technical progress in the stone industry, result in new specifications and these new specifications are often written without much consideration of the producer or his raw materials. In many cases then, producer research is the only solution for the maintenance of a market.

Another development which is not new but nevertheless is significant, is the continually broadening scientific and practical knowledge regarding the best utilization of stone products. Often such knowledge comes from fields unrelated to the stone industry itself, as for example the use of ground limestone in the field of animal nutrition. It is doubtful that a stone producer discovered the basic scientific data which makes possible the statement that "a growing calf needs the equivalent of 60 pounds of calcium carbonate per

year for its proper growth and a cow yielding 3 gallons of milk per day requires the equivalent of 160 pounds of calcium carbonate per year to supply the calcium content of the milk."¹

The rise and decline of the certain uses for stone is also a development of much consequence. Fifteen years ago the production of filter stone for sewage treatment works was unimportant in Illinois, at least production statistics fail to reveal the sale of such stone. Today filter stone is an important item to the Illinois stone industry. Another example, up till the closing years of the 19th century, the quarrying of building stone was an important industry in Illinois. After about 1900 production was very small but in the last 5 years the building stone industry has been revived and a tour around any of our larger northern Illinois towns will show why. The public and the home owner have become stone conscious.

One further recent development of note relates to the supply of soft wood. In the Lake States, Appalachian, and Southern soft wood areas, the demand for soft wood exceeds the supply. Only on the west coast does production surpass consumption. There can be no alternative other than a rise in the price of lumber in the Middle West to overcome the freight rates from the West Coast. Because the first cost of a wood home usually has been cheaper than one of stone, stone products or clay products, wood has been used extensively for construction despite the fact that a wooden structure is often conceded to be inferior from the standpoint of permanence and cost of upkeep. The first cost price difference is being leveled off, however, which means that stone, stone products and clay products are approaching a price parity with wood. Here then lies a new field for the stone and stone products industry. In all probability new developments in this field are just beginning. The field of house building is wide open to the stone and stone products industry providing it can provide a house which combines attractiveness, quality, durability, and price.

Considering then the status of the average stone quarry from the long range viewpoint and discounting the obvious effects of booms and depressions, it appears that the existence of the average quarry is a matter of losses of markets set over against gains of markets. The quarry which stands still merely balances the losses with gains; the forward moving quarry increases the gains beyond the amount necessary to offset the losses.

The question naturally arises in view of the changes in the quantities of stone used for different purposes, technologic progress, consumer preference, and the likely results of consumer research, what can the stone producer do to increase markets beyond probable losses? There is doubtless more than one way of accomplishing this end but research is unquestionably the most widely

¹Goudge, M. F., *Limestone and lime, their industrial uses: Min. & Met.*, vol. 18, No. 368, p. 372, August, 1937.

applicable means of so doing and probably in the long run the one which will pay the greatest returns.

The fact that this is an age where research goes hand in hand with progress requires no demonstration. There are, however, some factors regarding research that are sometimes overlooked, particularly research in a field such as stone which relates to a considerable variety of materials entering a multitude of different uses. In the first place, all successful modern research is carefully planned, not solely on the narrow plane of immediate needs, but on the broader base involving not only the requirements of the present but also the likely demands and possibilities of an unknown but eventual future. Through the plan of such research runs one central and ever present theme—the continuous, systematic, directed, accumulation, development and discovery of facts and ideas. These are the reservoir which may be tapped at will to meet new conditions and the larger it is the greater the confidence with which each new situation can be faced. And the continuity item should not be overlooked. By its very nature research is progressive and the most is accomplished by sustained research, not “fits and starts” research.

THE SURVEY'S RESEARCH PROGRAM

The State Geological Survey's research program on Illinois stone resources has been planned to encompass, in so far as the limitations of the Survey's field of activities permit, the conditions and developments previously mentioned. Because of the diversity and extent of the stone industry in Illinois, it is manifest that this program must be an all-industry research program rather than an individual quarry program. In a word, the major function of the program is the continuous assembling of data to be added to the reservoir of information regarding Illinois stone. The exact lines which receive the greatest attention vary from time to time according to the current needs. At the same time special studies which seem likely to contribute to the diversity of the stone industries or their products are likewise continually in progress.

It may be of interest to describe briefly some of the research projects under way and proposed for the year 1937-38. The work of cataloging the State's stone resources and their properties continues. With regard to limestones, recent work by the Survey has greatly enlarged the amount of information available concerning the Coal Measures limestones of the central and southern parts of the State. At the present time it is probable that data are at hand regarding the location of possibly 75 per cent of all the limestone outcrops in the State. Data regarding other stone resources is also multiplying both in quantity and quality so that in general there is emerging a comprehensive picture of the general nature and distribution of Illinois' stone resources.

In the case of limestone, it has been evident for some time as the fund of general data has been built up, that there is an ever increasing need for more and more detailed information. To meet this situation, careful, foot by foot sampling of typical and critical limestone exposures has been instituted. This procedure has been described at previous conferences and consists briefly of securing samples at intervals of one foot or less from the entire thickness of the exposure. Thus from a 100-foot face of limestone, 125 samples may be obtained. Notes regarding the deposits are taken carefully and in detail. The samples are tested in the laboratory first by rapid, rough tests, the results of which taken together with the field description of the deposits reveal many otherwise obscure data, and are the basis for the combination of individual field samples of like character into larger samples for more extensive and detailed laboratory studies. As a consequence, an intimate knowledge of Illinois limestone deposits is developing which has already demonstrated its practicability and will doubtless continue to increase in value with future developments in the stone industry.

Along somewhat the same line but emphasizing the property of weather resistance is a project recently started on the soundness of the dolomites in the general Chicago area. This is a cooperative project between the Survey, the Engineering Experiment Station of the University of Illinois, and the State Highway Division of the Department of Public Works and Buildings. The need for information regarding the probable weather resistance of limestones to be used for filter stone, building stone, concrete aggregate, railroad ballast, road metal and the like, has been felt for some time and two principal tests have been devised which are used in studying this property, namely, the freezing and thawing test and the sodium sulfate soundness test. These two tests, though not infallible when coupled with a study of the effects of weathering on the stone in natural outcrops, are the best means available for securing information regarding the probable weather resistance of a stone in advance of actual use.

The project under way is designed to be a thorough exploratory study of the soundness of the Chicago area dolomites. In recent years it has been found that Niagaran dolomite of that area, instead of being a single formation, is in reality divisible into four recognizable dolomite formations and that each of these four formations possesses reasonably uniform compositional characteristics. It is proposed to obtain representative samples taken at fairly close intervals from at least two typical, well separated exposures of each of these formations and likewise to secure any available data regarding the performance of the rock from each formation, under actual use conditions. The textural and petrographic character of these samples will be studied under the microscope and their soundness will be tested by the freezing and thawing test, the sodium sulfate test and possibly the magnesium sulfate

test. As a result it is believed important light will be thrown on the following questions:

1. Which of the Chicago area dolomite formations, in whole or in part, are likely to give superior service under exposed conditions?
2. How do the freezing and thawing, and sodium sulfate soundness tests of Chicago area dolomites compare as means of predicting soundness and how do they correlate with results of actual use?
3. What textural and petrographic properties characterize Chicago area stone having good soundness?
4. What criteria based on rapid laboratory tests such as acid etching and microscopic examination may be valuable in forecasting the probable weather resistance of the Chicago area dolomites?

While this project deals primarily with the Chicago dolomites it seems very likely that many of the results will be applicable, possibly with some modification, to other dolomites and limestones of Illinois.

Another major project which will go forward is a continuation of the investigation of the nature and properties of silicate melts resulting from the fusion of silica, alumina, lime and magnesia in varying amounts. Mention of this study has been made at previous conferences as the four-component system, especially in connection with the Survey's studies of rock wool making materials. During this last mentioned investigation only those combinations of the four components—silica, alumina, lime and magnesia—which were capable of producing rock wool were given primary consideration. It is now proposed to carry this work further to cover a wider range of compositions. Emphasis will be placed not on whether the fused products, that is the glasses, resulting from various combinations of the four components, are suitable for making rock wool, but rather it will include the finding of data regarding viscosity, thermal expansion, resistance to shock, and solubility in water and acids. The aim of the work is to determine definitely what products of possible commercial value can be produced by melting together in various proportions the compounds of the four-component system. Obviously these fused products will all be various types of glasses.

The question may well be raised why the four-component system, silica, alumina, lime and magnesia, is selected for study. The answer is that these four compounds are the chemical keystones of the greater part of the mineral resources of Illinois. Silica is the keystone in sands and sandstones, lime in limestone, lime and magnesia in dolomite, and silica and alumina in clays and shales.

Aside from glasses resulting from fusion of the compounds of the four-component system, basic data are being assembled to serve as a groundwork for a study of other means by which the members of this system can be united, such as by various combinations of heat, pressure and moisture. While the way is not yet clear, it is hoped that this groundwork will point out trails leading to the discovery of methods for synthesizing non-glassy products.

The balance of the Survey's program will be devoted to follow-up work on projects already completed, such as the study of methods for bleaching rock materials, and the investigation of rock wool making materials and to the cooperation with the Illinois stone industry in the solution of current problems as they arise.

SUMMARY

In summary then, the increase in the amount of and interest in research by the consumer, the general progress in the technical knowledge of the utilization of stone products, accompanied by more detailed specifications and demands for stone materials having special properties, and the rise and decline in the quantity of stone employed for certain uses, are significant developments in the stone industry. The likely result of these developments is the loss of one kind of stone business and the gain of another. The successful operator will keep gains in excess of losses. A continuing program of research is a lifeline to ensure continued gains. From the standpoint of raw material supplies and their greatest utilization, the Illinois Geological Survey is conducting a broad-gauged research program designed to keep the Illinois stone industry in front. The program includes the continued accumulation and cataloging of basic data regarding the stone resources of Illinois and their character, a detailed study of the "chemical stratigraphy" of Illinois limestones, investigation of the soundness of the Chicago area dolomites, and last, but by no means least, a comprehensive study of the glasses resulting from the combination by fusion of various quantities of the compounds silica, alumina, lime and magnesia—the chemical keystones of the stone resources of Illinois, together with an evaluation of the commercial possibilities of these glasses.

PROPERTIES OF ILLINOIS SOILS WHICH ARE RELATED TO THEIR NEED FOR LIMESTONE AND FACTORS CONTROLLING THE EFFECTIVENESS OF LIMESTONE¹

By

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INTRODUCTION

The Illinois State Geological Survey has expended no little energy in research directed to the betterment of producers of limestone and other mineral resources. The present speaker represents another State organization whose research program is carried out in the interest of Illinois farmers—the consumers of agricultural limestone. These two great industries, the producers and the consumers of agricultural limestone, do not stand against each other, at the opposite ends of a competitive “tug-of-war.” They are rather team-mates, pulling together in a common cause, and as such they may realize that what is profitable to one may turn out to be a benefit to the other. If the farmers cannot use limestone profitably, or if they cannot get the kind that they can use advantageously, the producers will have a difficult time selling it to them.

The purpose of this discussion is to attempt to portray some of the characteristics of Illinois soils upon which their lime need depends, and some of the factors that control the action of limestone in the soil, in order that we may get an accurate conception of the job that agricultural limestone is expected to do when it is applied to the soil.

SOIL DEVELOPMENT IN RELATION TO SOIL ACIDITY

The parent material of Illinois soils consists for the greater part of glacial debris, which served either directly as the raw material out of which nature fabricated our soils, or else, after being reworked and sorted by wind and water. This parent material was generally calcareous, that is, it was permeated with finely divided calcium carbonate. The rainfall during the soil-forming ages, and up to the present, has been great enough to provide water as a chemical reagent in the weathering of minerals and as a leaching agent for the movement of soluble and to some extent, insoluble products.

¹Contribution from Department of Agronomy, University of Illinois Agricultural Experiment Station. Published with the approval of the Director.

PROCESSES OF SOIL FORMATION

Soil formation can be imagined as consisting of three or more great waves or surges of weathering and other forces directed against the soil material, each having lasted through thousands of years. They did not come wholly one after the other, but with so much overlapping as to be largely concurrent.

One of the first of these processes was the dissolving of calcium carbonate and the leaching of it to greater and greater depths, finally carrying it out into the streams in drainage water. Another was the chemical breakdown of the silicate minerals, releasing their basic constituents, chiefly lime, in a soluble form to be lost in drainage waters unless it were protected in some way against leaching.

The insoluble product, colloidal clay, turned out to be the lime-absorbing material which protected it against leaching. Being insoluble, the mobility of this clay was low and it was retained in the surface, moving down into the subsoil only very slowly. The soil material was mildly alkaline so long as it contained calcium carbonate, having *pH* values ranging up to 8.0 or slightly higher. When the carbonate was first leached out the reaction was still approximately neutral and became acid slowly, only after long-continued leaching of the calcium combined with the clay. Other processes of the soil development are equally important but the ones mentioned are of particular interest in the study of soil acidity and liming.

BASE-EXCHANGE CLAY

As stated previously the protecting agent in the soil against the leaching of basic material is the colloidal clay. The clay particles have a surface attraction for the basic elements, calcium, magnesium, sodium and potassium, and also for hydrogen, the acid element. The capacity for adsorbing these elements is definitely limited in any given soil, and when an excess of one of them comes along in solution it pushes the others off and takes their place. This is called base exchange. Carbonated water (carbonic acid), resulting from the decay of organic matter, furnishes the principal acid hydrogen of soil water to displace the adsorbed or replaceable calcium. In these reactions the calcium forms a chemical union with the clay and we may call it calcium clay, just as the product of neutralizing sulfuric acid with calcium is called calcium sulfate. The hydrogen-saturated clay may be called hydrogen-clay or acid-clay.

When the calcium carbonate is first leached out of the soil, the soil is still neutral or slightly alkaline, because the clay is saturated, or nearly so, with calcium. It is only when the adsorbed calcium is finally forced off the clay particles—a much slower process—that the soil gradually becomes acid; and the lower the degree of base-saturation becomes, the more tenaciously is

the remaining calcium retained. If the base absorbing capacity of a soil is approximately 80 per cent saturated with calcium and other bases, the remaining 20 per cent being acid hydrogen, the soil is neutral. If it is more than 80 per cent saturated, it is alkaline, and if less than 80 per cent saturated, it is acid. These values are not the same for all soils. Many soils are neutral for instance, at 75 per cent saturation.

In general, the soils of northern Illinois are younger than those farther south. Consequently, one frequently finds soils in the northern third of the State which are calcareous at the surface, and quite generally calcium carbonate is found within less than five feet of the surface. Also, soils which have lost their calcium carbonate, but which are still approximately neutral, are not uncommon. As one goes southward, carbonates are found to have been leached out to greater and greater depths. The surface soil has become more intensely acid and the acidity extends deeper than in the younger soils to the north. Figure 2 shows the base-exchange relations in the surface soil of a number of the most important and extensive soil types in Illinois.

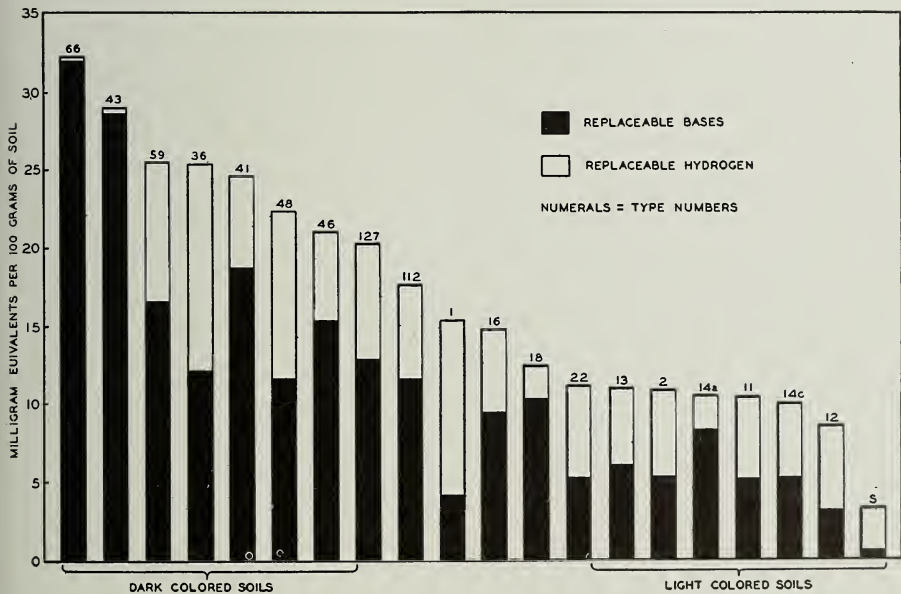


FIGURE 2.—Exchange capacity and degree of base saturation in some Illinois surface soils.

Knowledge of the regional variations in soil acidity is of only limited value to the farmer in determining his own liming needs. Some soil types are fairly uniform in lime requirement throughout their extent. Others are quite variable. Moreover, there may be several soil types on the same forty-acre field. Because of the local variations in lime needs, farmers of Illinois have found it profitable to test before liming. Significant savings have been

made not only by avoiding the liming of sweet soils, but also by not sowing clover seed which would have been wasted on acid soils. The educational value of soil testing has been proved also. Many a farmer received his first stimulus to use limestone by collecting samples from his field, testing them with his own hands in a neighborhood soil-testing meeting and drawing a soil acidity map of the field.

LIMING A SOUR SOIL

The limestone in a soil actually does no good until it dissolves. The most important solvent in the soil is carbonated water or carbonic acid. When limestone dissolves in carbonic acid the product is calcium bicarbonate. Magnesium, which would be provided by dolomitic limestone, shall be considered as taking part in these reactions as well as calcium, and forming the corresponding magnesium compounds. When limestone is mixed with an acid soil it first dissolves as calcium bicarbonate and the calcium then displaces the absorbed hydrogen from the acid clay particles changing it to calcium clay. The conditions which control the rate of this change are extremely important from a practical point of view. It can be made to take place instantaneously, as when a solution of a calcium salt is poured through a thin layer of soil on a filter. Professor W. H. McIntire, in Tennessee, found that when the limestone was reduced to a fine powder, very thoroughly mixed with moist soil and then kept moist but undisturbed, seven weeks were required to effect the complete interaction between the soil and the limestone. When the farmer applies limestone it is neither reduced to a powder nor thoroughly mixed with the soil. Under field conditions the complete reaction between the soil and limestone may, and frequently does, require two to four years. But it is not necessary that the neutralization of the acid soil be entirely complete in order to secure satisfactory growth of acid-sensitive crops such as alfalfa and sweet clover. An understanding of the conditions which must exist for their growth necessitates a study of limestone fineness. The results of work carried out at the Illinois Agricultural Experiment Station will throw some light on this question.

RELATION OF PARTICLE SIZE TO EFFECTIVENESS

It has been pointed out that the neutralization of acid soil consists of changing its acid-clay to calcium-clay, the calcium being derived from applied limestone or other liming material. It should also be noted that this process must take place for the most part while the soil is undisturbed, for even if a cultivated crop such as corn is being grown any particular portion of soil in the field is stirred by means of tillage implements only some half-dozen times in a year and each time during only one or two seconds, while the

harrow or cultivator is passing along. It is obvious that under these conditions the reaction between limestone and soil must depend upon the diffusion of the dissolved calcium from the limestone particle into the soil until it is fixed by a clay particle. The next calcium to dissolve after the first film of soil around the particle is neutralized must dissolve in essentially neutral conditions and pass through this neutralized film to reach more acid soil to be neutralized. The first question to be answered is, "How far out from a limestone particle will the calcium penetrate into the soil and neutralize it?"

To answer this question a polished slab of limestone was buried in moist, acid soil in a jar and sealed to prevent drying out. Several of these were set up and examined one by one after varying periods of time, during which they were kept at approximately constant temperature (about 70° F.). The results are shown in table 1.

TABLE 1—PENETRATION OF NEUTRALIZING EFFECT OF LIMESTONE INTO UNDISTURBED SOIL

Time after placement of slab (Days)	Upward from slab		Downward from slab	
	Distance A (Cm.)	Distance B (Cm.)	Distance A (Cm.)	Distance B (Cm.)
259.....	0.3	0.6	0.2	0.5
528.....	0.8	1.7	0.4	0.7
Boulder ^a.....	.....	.....	0.8	1.7

Distance A—Distance of effective, but not complete neutralization.

Distance B—Greatest distance at which a measurable reduction in acidity occurred.

a—Measurements made under a small natural limestone boulder found buried about two feet below the surface in an apparently virgin roadside area in Champaign County. It had evidently been in place a great many years.

These data indicate that each particle of a limestone application quickly surrounds itself with a roundish mass of more or less neutralized soil (completely neutralized at the center) which in the course of a year grows to a size ranging from one-half inch up to one and one-fourth inches in diameter. Whenever all of these neutralized masses of soil overlap, the soil will be completely neutralized. But this may require three or more years, as experimental studies on field soils have shown.

An important consideration in limestone fineness is thus the number of particles in a given volume of soil to serve as nuclei for the development of these neutralized areas in the soil mass. As an illustration, suppose a 1/4-inch cube of limestone were reduced to 100-mesh cubes, i.e., particles which would just pass through a 100-mesh sieve, with no dust or finer particles included. Each particle would measure 0.0058 inch on a side. One 1/4-inch cube would make approximately 80,000 such particles, capable of forming 80,000 neutral centers in the soil if perfectly distributed. But to get 80,000 neutral centers in the soil by using 1/4-inch particles of limestone would require 120 pounds of them.

Another method of showing the relation of particle size to neutralization of acid soils is to compute the volume of soil which each limestone particle would have to neutralize in a given application. This has been done for a two-ton-per-acre application for the various size grades and the results are shown in figure 3. It is significant from a practical point of view that all sizes up to and including the 8-mesh (0.093 inch) are comparatively high in efficiency, as each particle is required to neutralize less than one cubic inch of soil, while the 4-mesh size is highly inefficient. A two-ton application of 4-mesh limestone (0.186 inch) provides so few particles that there is only one particle to each $6\frac{1}{2}$ cubic inches of soil, and with $\frac{1}{4}$ -inch particles there would be one to each $15\frac{1}{2}$ cubic inches of soil.

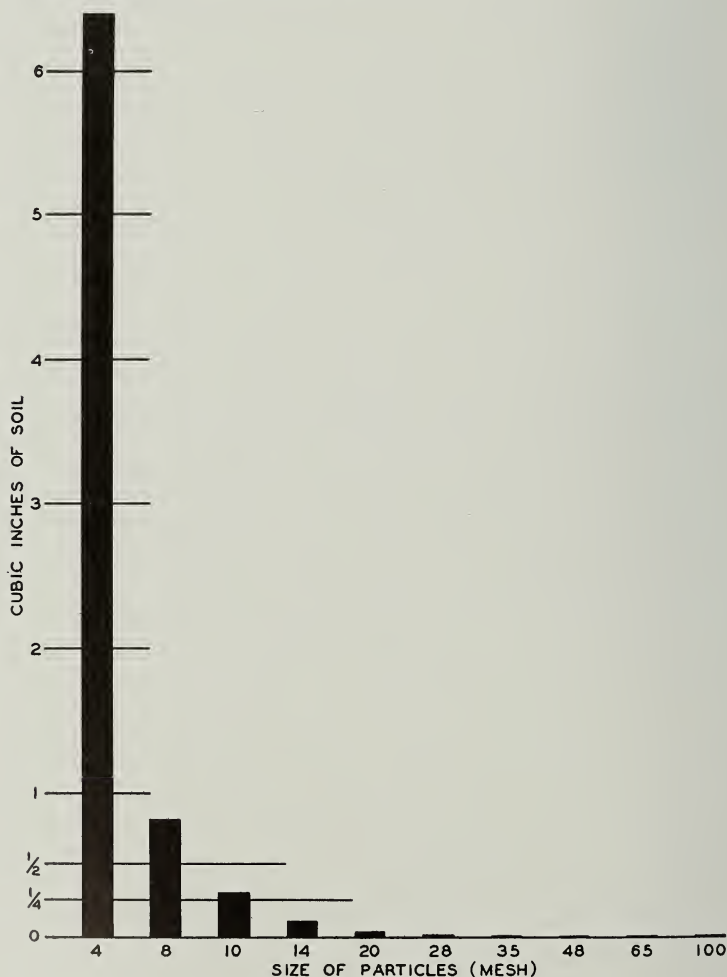


FIGURE 3.—Relation of particle size to space distribution of limestone particles in an application of two tons to an acre.

LIMESTONE SCORE CARD FOR FINENESS RATING

The preceding discussion has emphasized the fact that from the standpoint of actual value to the farmer the evaluation of limestone as to fineness should consist of a method of dockage for very coarse material rather than a method for drawing fine distinctions between different sizes toward the fine end of the scale. Such a score card should also provide for expressing the fineness rating of a limestone by means of one figure rather than by a series of percentages of the different sizes present in the sample. The score card which has been in use in Illinois for some years was devised with the above aims in view. It appeared desirable, in working out the details, to take into account certain other matters as well.

Screen test data were available on some 200 carloads of commercial limestone that had been sold to Illinois farmers, so that it was possible to prepare, by accurately combining different size fractions, a limestone which was similar to the average commercial limestone in use in the State. This was done with five different limestones representing the different geological formations which were furnishing the bulk of Illinois agricultural limestone. These were studied over a period of five years in soil cultures in which sweet clover and grain crops were grown. At the same time they were compared with some of the different size grades used separately. Not only was the growth of crops, particularly sweet clover, determined, but also the rate at which the limestone disappeared and at which the soil acidity was neutralized. As a result of these studies it was found that the limestone of the average fineness then in use rated approximately 75 per cent as effective as finely ground limestone (100-mesh). This information furnished a basis for a score card calibrated in terms of the actual value of the limestone on the farm, since the starting point in the construction of the score card was the assignment of a value of 75 to limestone of the average grinding. The score card is as follows:

Percentage of sample	Multiply by	Product
Thru 100-mesh ^a	1.15	.....
Thru 48, over 100-mesh.....	1.05	.....
Thru 28, over 48-mesh.....	1.00	.....
Thru 14, over 28-mesh.....	.95	.....
Thru 8, over 14-mesh.....	.80	.....
Thru 4, over 8-mesh.....	.33	.....
Over 4-mesh.....	0	.....
Sum of products.....		.....

^a In the Tyler standard screen scale used, the opening of the 100-mesh is 0.0058 inch on a side. In each succeeding screen of the series the size of the opening is twice that of the preceding one.

The sum of the products obtained is the fineness rating of the limestone. It will be noted that this is not a severe score card. Everything finer than 8-mesh receives a high rating, and the very coarse particles are severely discounted. The chief criticism is that the finest fractions are overrated. This was necessary in order to offset the dockage on the coarsest fraction and bring the rating on the entire sample up to its true value as demonstrated by crop response. The use of this score card for several years has brought added conviction that the method gives an accurate evaluation of agricultural limestone for use under Illinois farm conditions. Its use also may have been partly responsible for the improvement in fineness of agricultural limestone during recent years. Illinois producers have raised the average fineness rating of commercial agricultural limestone from 75 to 84 during the past 7 years. Some further improvement is still needed, but it is debatable whether Illinois agriculture would profit by increasing the average rating above 90.

CHEMICAL QUALITY OF LIMESTONE

The matter of chemical quality scarcely needs discussion. Limestone is of value only in so far as it will correct acid soils and no amount of preparation can raise this value. Its value in this respect depends on its content of calcium carbonate, or the equivalent in magnesium carbonate, and is expressed as calcium carbonate equivalent (C.C.E.). The cost of quarrying and grinding precludes the practicability of working low-testing deposits.

AMOUNTS OF LIMESTONE NEEDED

The amount of limestone needed in any given case is conditioned upon the acidity of the soil. The final effect should be to saturate the base exchange clay (base-capacity) to the extent of approximately 80 per cent with calcium, since this degree of saturation is sufficient to assure a neutral soil reaction in practically any soil. It is entirely unnecessary to have an excess of free limestone (calcium carbonate) in the soil, and such an excess, if present, is much less resistant to loss by leaching than is the calcium contained in the calcium clay of a neutral soil. For satisfactory growth of acid-sensitive crops during the first year or two after liming, it is essential that neutral centers about the limestone particles be numerous enough that plant roots come in contact with them. Experience has indicated that applications which are sufficient for final neutralization of the plowed depth of the soil usually bring good stands of clovers or alfalfa within less than a year after application.

LIGHT LIMING

Light liming consists of drilling limestone in the row with clover seed. The limestone is applied through the seed hopper of the grain drill (or through the fertilizer attachments where drills have such equipment), while

the clover is seeded through the grass seed attachment. The tubes of the grass seed attachment are run into the grain tubes, thus carrying the clover seed into the drill row in contact with the limestone. A careful setting of the drill is necessary to prevent covering the seed too deeply. This method of liming requires only 500 pounds of limestone an acre. The limestone should all pass an 8-mesh screen, including fines but no additional advantage has been found by using finely pulverized material. Light liming owes its success to the fact that the neutral soil zone around the applied limestone is near the seeds so that the roots of the seedlings are fairly certain to find neutral soil. In cases where the soil mass away from the neutralized zones is highly acid the method has not been successful. The chief advantages of light liming are in getting quick results and in getting a crop of clover or alfalfa with a very small amount of limestone. Its chief disadvantage is that it does not correct the acidity of the whole soil mass and is good for only one crop, whereas an adequate application of limestone is good for 10 to 15 or more years.

KINDS OF LIMESTONE

There are many kinds of limestone. They differ not only in chemical composition, but also in hardness, porosity, character of fracture on crushing, rate of solubility and other properties. These variations have resulted from the conditions under which they were formed and one would expect that the principal differences might be found by comparing material from various geological formations. The five sources previously referred to are believed to include most of the limestone used in Illinois. They are the Ste. Genevieve, Burlington, St. Louis, Niagaran and Coal Measures. Of these, only the Niagaran contains enough magnesium to be considered dolomitic.

Since limestone which has not dissolved has performed no function in the soil, the rate of solubility would be expected to be an important property having to do with its rate of becoming active in the soil. The chemical approach to this problem would be to determine the rate of solubility under controlled laboratory conditions with other variables eliminated. This has been done, using 20-40 mesh limestone and 0.4 normal acetic acid with the results shown in figure 4. Similar results were obtained with the other sizes. The rate of solubility of the dolomitic stone is shown to be very much slower than that of the others. These results are presented to show how completely erroneous may be the interpretation of legitimate results of a carefully controlled experiment if the experiment is not so designed as to answer the real question at issue. The real question at issue here is the behavior of limestone in the soil. When limestone particles are placed in undisturbed soil, as is done in practice, instead of in an acid which is being stirred, the rate at which it dissolves and neutralizes the soil is almost completely dominated by the rate of migration of dissolved calcium through the

soil away from the limestone particle. The actual rate of solubility becomes a very minor affair. Moreover, both the dolomitic and high-calcium limestone particles in the acid soil become surrounded very soon by a layer of neutralized soil so that the rates of solubility of both limestones in this neutral environment are so greatly retarded that differences of rate become insignificant.

The relative solubility rate in soil was determined for the Niagaran dolomitic limestone and the four high-calcium limestones by measuring the amount of undecomposed carbonate remaining in the soil five years after the applications were made. Since the high-calcium limestones were essentially alike in their behavior, the results from only one are given in table 2 along with those for the dolomitic limestone. The soil used was an acid surface soil from Cisne silt loam having a lime requirement of 7,000 pounds calcium carbonate an acre. The "average commercial" limestone addition was made by screening the limestone into a series of size grades and then recombining them in separately weighed portions of each size for each individual jar so that all jars contained not only the stated amount of limestone but also exactly the same proportions of all the different sizes.

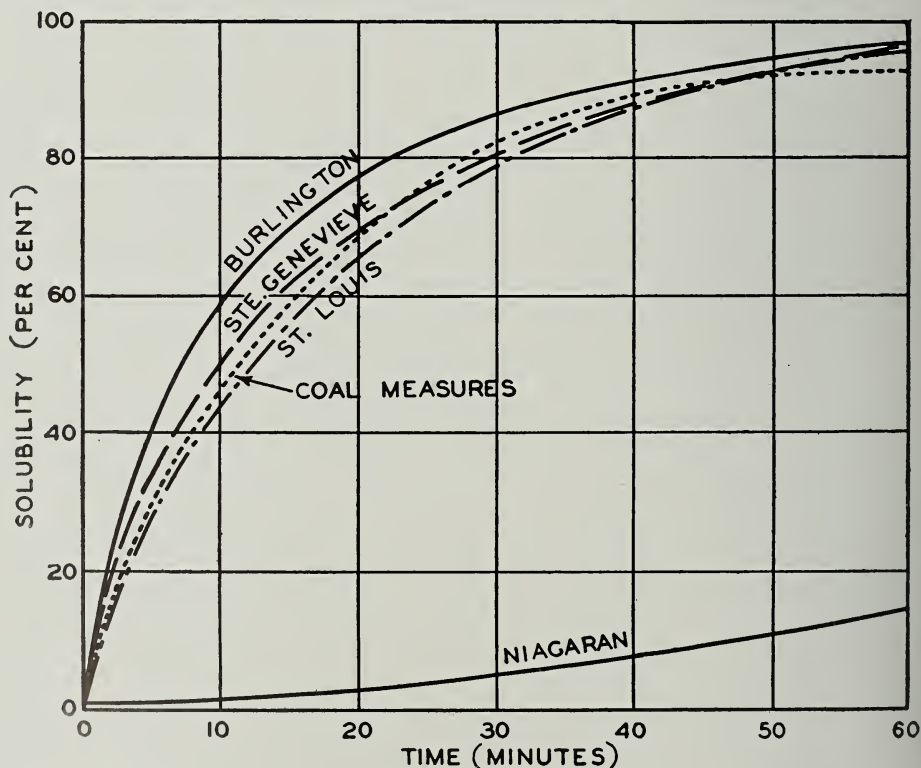


FIGURE 4.—Relative rates of solution in acid of limestones of different geological formations. (20-40 mesh limestone in 0.4 N acetic acid, with stirring.)

TABLE 2—UNDECOMPOSED LIMESTONE REMAINING AS CARBONATE AFTER FIVE YEARS IN THE SOIL, WITH DIFFERENT APPLICATIONS

Kind of limestone	Amount of original application remaining from an acre-application					
	3,000 lbs. ^a 4-5 mesh (Per cent)	3,000 lbs. ^a 8-10 mesh (Per cent)	3,000 lbs. ^b 8-10 mesh (Per cent)	10,000 lbs. average commercial (Per cent)	5,000 lbs. average commercial (Per cent)	7,000 lbs. 100 mesh (Per cent)
Dolomitic.....	97	81	53	40	20	7
High calcium.....	81	67	39	24	19	6
Difference.....	16	14	14	16	1	1

^a Accompanied by 7,000 lbs. an acre of 100-mesh limestone.

^b Used alone.



FIGURE 5.—Sweet clover growth with 5 tons (above) and 2½ tons (below) of limestone. Kinds of limestone, left to right: Ste. Genevieve, Burlington, St. Louis, Niagaran, Coal Measures (no limestone).

Two facts brought out by these results are worthy of comment. One is that in the coarser size-range high-calcium limestone dissolves in the soil approximately 15 per cent faster than dolomitic limestone, but this difference does not occur in the finer size range. The other is that with commercial limestone (4 mesh down) a similar difference (16 per cent) in favor of high-calcium limestone occurs where the application exceeds the lime requirement of the soil so that the soil is approximately neutral at the end of the five-year period, but the two types of limestone become equal in rate of solution (20 and 19 per cent, respectively, remaining) where the application is less than the lime requirement of the soil so that the latter remains acid throughout the five years. In comparing acid solubility with soil solubility it will be noted that whereas in acid the high calcium limestone dissolves more than six times as fast as the dolomitic type, this difference is reduced to an advantage of only 15 per cent for high calcium stone in the coarse size range and no advantage in the fine range. The practical interpretation of this study would appear to be that for equal results in the field, if just the amount to meet the lime requirement is used, the dolomitic limestone should contain a somewhat smaller proportion of material at the coarsest end of the scale. As a matter of fact, in actual practice farmers generally use an excess above the minimum requirement so that either type of stone produces the results desired in the growth of sweet clover, alfalfa, or other acid-sensitive crops.

The interpretation stated above is supported by the growth of sweet clover in these experiments. Figure 5 shows the adequacy of all five limestones when used at the rate of 5 tons an acre and the inadequacy of all of them at the $2\frac{1}{2}$ -ton rate, the sweet clover having been seeded immediately after applying the limestone. The growth of sweet clover in the same soils three years later is shown in figure 6.

USE OF LIMESTONE IN ILLINOIS

So far as is known the first carload of limestone delivered to an Illinois farmer was shipped in September, 1906. The tonnage has increased steadily, except for a decline during the recent depression, to more than a million tons in 1936. No other state uses so much agricultural limestone. It owes its popularity in considerable measure to the success of the limestone-sweet clover combination in soil improvement, and the sweet clover acreage has kept pace with limestone tonnage. But the limestone used in Illinois up to the present time has not kept pace with removals from the soil in the farm products sold and in drainage waters. Of our 20-odd million acres of cropped land, probably 15 million acres need liming, and to supply this need would require a minimum of 30 million tons of limestone. If our farmers were to apply it at the rate of 2 million tons a year, evidence now at hand indicates

that the time would be ripe at the end of the 15 elapsed years to start liming the first limed areas a second time. It appears that natural forces and man's farming the land are combining to provide a continuing demand for agricultural limestone for many years to come, and the evidence of field experiments as well as of farmers' experience leaves no doubt that the crop increases and better balanced farming systems, which its use permits, will make it profitable.



FIGURE 6.—Sweet clover growth with 5-ton and 2½-ton applications of different limestones. This clover grew three years after liming.

CURRENT DEVELOPMENTS IN STABILIZED GRAVEL AND CRUSHED STONE ROADS

By

ERNST LIEBERMAN

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The present day acceptance of the word "stabilization" may refer to the natural subgrade or to a surfacing material placed upon that subgrade, but in this paper I shall deal exclusively with the so-called stabilized base or surface course of crushed stone or gravel.

The stabilized road as designed and built actually involves nothing essentially new in materials or construction except the application of some sound basic characteristics and theories affecting the blending of the materials and then proper construction methods and maintenance to obtain a resulting product in which the voids have been reduced to a minimum, in which enough clay has been introduced to give satisfactory binding qualities, and which will have a density to the highest degree possible to prevent the entrance of capillary water. We find ordinarily a compacted weight of 4,000 pounds per cubic yard.

A study of the theory of design and nearly four years construction experience have proved that the idea is based on sound and accurate theories of proportioning and that we have secured a type of surfacing most satisfactory for moderate traffic from the standpoint of rigidity, strength and surface smoothness.

Experience has proved that certain features in the original specifications may be eliminated or altered in order to get the cost of this type of pavement within the economic principles for a road of this character without seriously affecting the resulting product. An ability to vary the gradation of aggregates to a limited extent affords an exceptional opportunity to utilize materials from the ordinary commercial pits and to develop local gravel and stone deposits at a very reasonable cost.

The theoretical stabilized mix is one in which there is just enough of the sand and clay or soil mortar to fill the voids in the coarse material, with a slight excess. The introduction of the clay is not a new idea; in fact it has been rather common for many years, but a study as to the proper quality and amount is entirely unique in the case of the stabilized road and there is a very definite theory governing its use. Stability in any wearing surface may be defined as resistance to lateral flow under load. It depends upon shear strength, which in turn depends on the combined effect of internal friction and cohesion. Sand, when dry, is unstable but when a small amount of water is added it attains a high degree of stability. Clay, on the other

hand, with a small percentage of moisture, will carry almost an unlimited load but it entirely loses its carrying capacity when wet. The problem then is to combine them in the correct proportions to eliminate the undesirable characteristics and to utilize the desirable ones to produce the best all-year stability. In doing this, certain basic soil properties must be given consideration in the design of any mix; namely, internal friction, capillarity, cohesion, and compressibility, and of these basic points, internal friction, cohesion and retarded capillarity are essential for stability. It is essential that the soil mortar; that is, the combination of clay and sand shall not expand excessively when wetted, otherwise the internal friction will be destroyed. Since internal friction is a function of the sand and gravel grains but cohesion is not, the clay lends the necessary cohesion. Capillarity is harmful to the mass in that it tends to break up cohesion and reduce internal friction. Therefore clay, with its low rate of water flow, tends to reduce the amount of capillary water entering the mixture. On the other hand, clay is expanding material and the amount must be strictly limited in order to prevent undue expansion and breaking up when wet.

Our own experience has proved that it is generally better to use a little less clay than too much, and whereas ten to twenty per cent was accepted at first, ten to twelve per cent is now generally regarded as more desirable. A high percentage of clay often results in a dangerously sloppy surface in wet weather.

The function of the calcium chloride is to attract moisture, particularly to the clay. This preserves its cohesion, thus preventing raveling and surface dust.

A question is often raised as to relative values of broken stone and gravel, and local and commercial products. We have had experience with all. Another question is whether or not the soil mortar or fines represented by the screenings and dust in a broken stone mix can be considered of equal value to the mixture of sand and clay in a gravel mix. There is a divided opinion on the theory; nevertheless from the standpoint of construction results, a mix of broken stone, screenings and stone dust meeting the gradation as shown in the stabilization chart (the stone dust taking the place of clay) has proved satisfactory (see fig. 7).

The chart shows the original stabilization band (ruled down to left) and the other band (ruled to right) indicates our present common practice. It has not been considered particularly detrimental to the mix to allow slight variations even from the latter band, particularly when it is desirable to permit the use of local material—either commercial or roadside products—where economics justify. It is a fact well proved during the past few years that an analysis of many samples of our own local deposits throughout the State indicates that they fall close within the band, the

GRADATION OF AGGREGATES

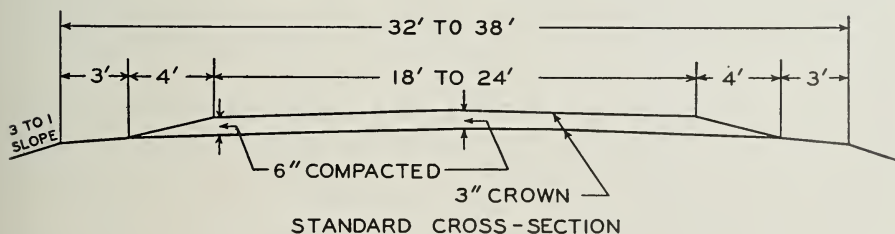
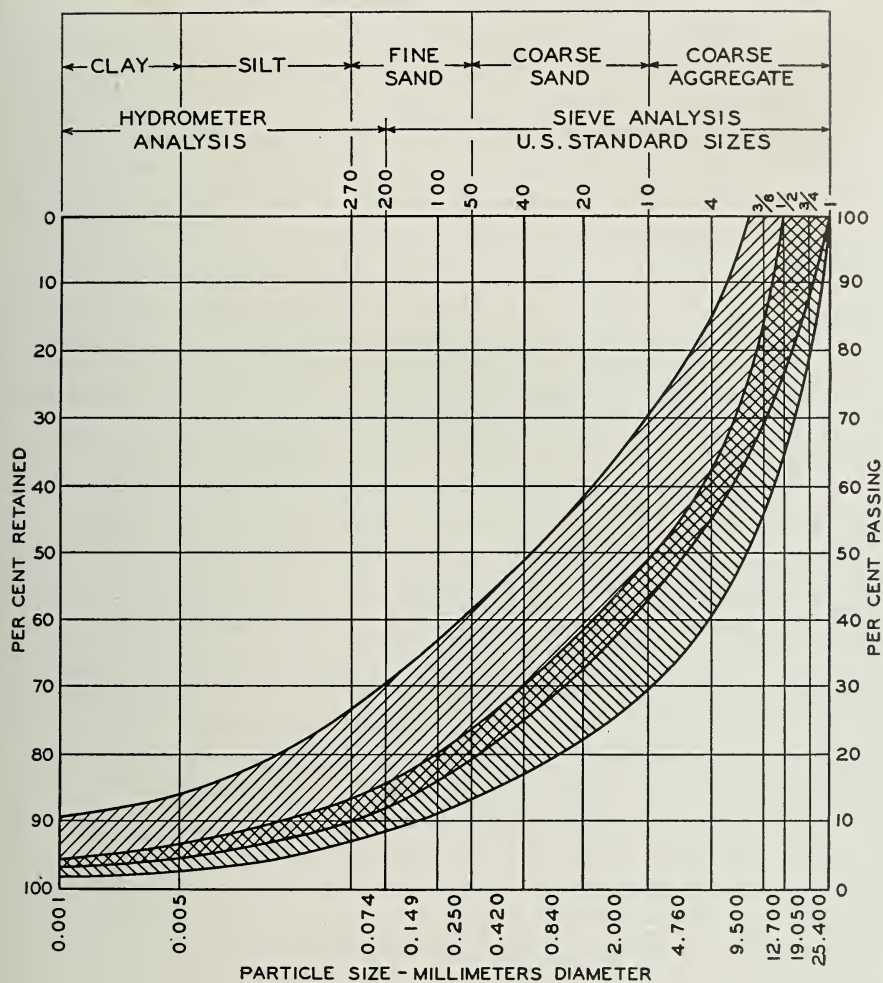


FIGURE 7.

usual tendency being an excess of fines, which can be removed by screenings or by adding coarse material.

Experience has also proved the undesirability for an excess of the fine sand combined with a low percentage of coarse aggregate, and it is generally believed that the upper limits may well be avoided and that for a specific mix, a uniform curve is more effective.

The comparison between local roadside pits or quarries and commercial plants is largely a study of economics. Oftentimes a local gravel pit can produce a correct mix with enough overburden to eliminate the necessity for the separate introduction of the clay; likewise many quarries control their screenings and dust content to a proper mix. On the other hand, the production cost of the established commercial plant is always a factor, and a shorter haul from the railroad siding compared with a long deadhaul from the local plant may offset the railroad rates. The demand for a large volume of aggregate for stabilized roads may prove the logic of the producer adding the proper amount of fines and clay before shipping to the job, and it is my opinion that as soon as he realizes the field which is now open for him to furnish materials for bases and surface courses of this character, he will meet this problem. However, in this connection permit me to sound a note of warning; we are dealing with the secondary road, which must be low in price. The producer must not introduce intricate equipment and expect to get an advanced price for material. To my mind, any increase in price naturally discourages the development of this particular type of road. I urge an intensive study of a proper means of introducing and blending the aggregate in the proper proportions at the production plant. Whether this can be done economically is still a question. If it can, expensive construction operations can be markedly reduced; if not, the more costly road or plant mix must be developed to the lowest economy.

The theory of construction is a thorough mix on the road if a perfect mixture cannot be obtained at the plant; spreading in layers to permit proper compaction; application of water to obtain proper moisture cohesion and aid compaction; a kneading or compacting of each layer to completely interlock the essential ingredients and reduce the voids to a minimum (thus bringing in the three soil properties—internal friction, cohesion, and compressibility); and finally, the application of the chloride to create a moisture attracting agency to prevent raveling and dust.

If it is possible to get a natural mixture, including the clay, the material may be dumped directly on the grade in piles correctly spaced to secure proper thickness, but if an artificial mix is necessary, the mixing is generally done on the grade.

Since most producers can furnish a correct mix of coarse and fine aggregate, the usual procedure is to spread the first layer of aggregate over about half of the subgrade and then add the proper amount of clay. It is always

best to pulverize the clay at the pit, if possible, as it saves time and secures a more uniform mix. The entire mass is then mixed together by blading back and forth across the grade, and finally leveled down to proper width and cross-section. Wetting and rolling follow. The successive layers are built up in the same manner as the first. Care must always be taken to keep the subgrade from being incorporated during the mixing.

Layers of approximately two inches seem to give best results, which is an axiom for the compaction of any material, earth, gravel or stone. A minimum thickness permits complete and thorough interlocking of the particles which may not be obtained with thicker layers because the effect of the roller will not be transmitted through the entire mass, thus causing voids at the bottom.

The roller best adapted is the truck-tire type recently developed on the same principle as the dual truck wheel; that is, six or eight wheels with pneumatic tires strung on an axle which supports a body, this machine propelled by truck or tractor. It produces the effect of a series of truck tires which I believe secures better compaction than the ordinary roller; the very nature of a tire secures an excellent interlocking of the materials.

Traffic, if not too heavy, and if not concentrated in one rut serves much the same purpose as the roller.

One of the uncertainties to the contractor in figuring a job is the hauling, spreading, and intermixing on the grade of the various aggregates, particularly the clay, and to eliminate delays and standardize production, several machine mix methods have been developed. In several instances a 27-E concrete mixer has been used successfully but production is limited. One machine mixer which picks up the windrowed material from the subgrade and runs it through a pugmill has proved very satisfactory. The best piece of equipment used in this State to date is the Pioneer plant mix unit. The advantage of this particular machine is that it combines the sand and coarse aggregate, runs the clay through a shredder and then mixes the entire mass with water and calcium chloride in a pugmill, delivering the finished mixed product into a storage bin, from which it is dumped into trucks and hauled to the subgrade. The only road operation necessary is the spreading in layers and rolling. One such outfit in 1936 laid 27 miles of 18-foot road and this year has a program of 38 miles. The resulting mix is more satisfactory and the cost markedly lower than a road mix. Economics of construction must be given still further study and let me repeat: A correct gradation of all component materials by the producer would eliminate all the expensive job mixing.

Whereas the flake calcium was originally applied to the finished surface, it has been found more desirable now to mix it in the top layer. The use of salt in place of calcium chloride has proved economical and the action is satisfactory.

It has been definitely demonstrated that the stabilized road will not compact thoroughly or "make" except under continued traffic and at least 30 days maintenance should be provided to work out soft spots and insure proper interlocking of the aggregate. Continual blading, the application of water, and some rolling may be necessary. As a matter of fact, I have come quite firmly to the conclusion that any stabilized road should go through a winter's traffic before we can safely say that it is thoroughly compacted with the reduction of the voids to a minimum.

Blading or dragging at the proper time is essential for the maintenance of any stabilized road and a firm smooth surface quite free from loose material results. Three applications of calcium— $\frac{3}{4}$ pounds per square yard are recommended in May, July and September.

The chart also shows our latest cross-section. The feathered edge shoulder of gravel is believed to be of advantage in keeping free water from damaging the pavement: that is, surface water cannot be trapped on the subgrade by a more or less impervious earth shoulder. This is especially important during the early spring thaws when all gravel or broken stone roads are proverbially soft.

The earth shoulder has a particular disadvantage under maintenance where the drag or blade is bound to deposit a certain amount of earth on the edges of the road metal, resulting in a slippery surface which is invariably avoided by traffic, thus restricting the traveled roadway.

The cross-section as shown gives a very wide and ample road, tending to distribute traffic; this tends to compact uniformly the entire surface width and is of distinct advantage when a bituminous surface is contemplated—an otherwise soft edge tends to a raveling of the "blacktop".

Naturally the one interesting question to all of us is the place, the scope, and finally the future of this particular type of construction. Without reservation I refer to the secondary road system, which seems to be well established now in our highway program. It has been recognized emphatically not only by our Governor, but also by the Federal Government through the fact that each of the Federal relief grants for highway purposes, the 1934 and 1935 N.R.A. and the 1936 W.P.A. specified that a definite percentage of the grant must be spent for secondary highways.

In line with such a program and realizing the necessity for an economic study of the entire highway system of the country in order to properly classify roads according to present traffic and future importance, the Federal Government in 1935 appropriated a definite sum of money to be expended on a national planning survey of the highway system of each state. In our State practically all of the field work has been completed and the great mass of information is now being correlated—so as to be utilized at once in the economic design of highways capable of handling their present day traffic, yet still looking ahead to their future development—not wasting funds

on roads which must always be only feeders, and likewise not building something which may be a total loss when in a few years increased traffic demands a more modern construction.

The secondary system fits well into the picture as the logical place for the stabilized road because of its moderate cost and reasonable maintenance under moderate traffic. It will handle satisfactorily the present traffic, and as time goes on and a higher type of surfacing is required, it can be utilized in practically its entirety as a base course for some type of bituminous surfacing or even as a stable base or subgrade for Portland cement concrete.

As to the farm-to-market or small feeder roads of very light traffic, the stabilized type may well have a place in their construction, dependent entirely upon the economy of the materials and construction. Roads of this character justify some sort of gravel or broken stone surfacing, and if the stabilized road can meet competition with the so-called traffic-bound, it is distinctly as satisfactory.

The 1937 session of the State Legislature, to meet Federal legislation, authorized the Department of Public Works and Buildings, Division of Highways, to lay out a ten thousand-mile system of Federal secondary roads, which henceforth will serve as a basis for future construction.

Federal appropriations for the years 1937 and 1938 specify approximately one million dollars each year to be spent on the secondary system, with the understanding that the State will contribute a similar amount. What the future will bring is yet a problem, but it is thought that the establishment of a definite system and the policy of a specific appropriation presupposes its definite place in our future Federal and State program.

While the stabilized gravel or broken stone road has not been adopted by all counties, nevertheless the work which has been done under State supervision has served in a large measure as an object lesson with the result that many of the counties have begun to appreciate the advantages of this particular type of construction; yet I may say without fear of contradiction that the one thing which has held back its adoption is economics. Certain refinements in materials and construction practices have a tendency to add slightly to the price, which is an important factor with a county limited in funds. Bear in mind, too, that on many of the county roads traffic does not, and probably will never, justify the necessity for anything more than two or three inches of gravel to give adequate service 365 days in the year.

A few figures may be of interest to the material producers. The State under its own supervision has constructed in the past four years (1934, and including 1937 estimated), 587 miles of gravel and crushed stone roads, of which 444 miles have been stabilized. For the cross-section shown on the chart we estimate 2,347 cubic yards, compacted measurement, of aggregate for

a 20-foot width, including the gravel shoulders, and 2,151 cubic yards for an 18-foot width.

Gravel or broken stone road construction by the counties and cities, with the motor fuels tax (M.F.T.) funds, is even more significant as the figures for the past four years will show:

1934—313 miles	1936—659 miles
1935—389 miles	1937—600 miles (estimated)

On county and city work quantities vary between rather wide limits, but a safe average would be 1,500 cubic yards, loose measurement, per mile.

Our own program on the new Federal secondary system from the 1937 appropriation contemplates 139 miles of gravel or broken stone road, and 1938 should be closely the same. The future on the county and city M.F.T. work, judged by the past, may easily average 500 miles per year. These rather approximate estimates should show the aggregate producers the present trend.

In conclusion:

A. An analysis of the traffic on our highway system indicates that we have many, many miles of secondary roads which will carry only moderate traffic—say less than 500 vehicles per day.

B. On roads of this character, a road of broken stone or gravel seems the economical type, for its first cost, reasonable maintenance, and its adaptation as a base for future improvements when required.

C. Thus far, our own experience justifies the stabilized aggregate, but its economic development calls for a thorough cooperative study between the engineers of the highway department, the material producers, the equipment manufacturers, and the contractor.

D. Economy in construction of this type of road involves a more or less elastic specification to utilize such local resources as we have available, the development of equipment which can reduce construction costs, and the realization by contractors that this type of construction is permanent and that they are economically justified in equipping themselves with proper machinery to handle a reasonable program.

E. If we all enter into the problem with the idea of getting a road in terms of cost equal to its value, such a type will be justifiable. On the other hand, if the price figures a little beyond the logical value, the utilization of this particular type will not prove successful.

F. We have before us a definite secondary road program utilizing Federal and State funds; likewise a continued yearly expenditure by the counties and cities of their M.F.T. allotments which approximate \$7,500,000 to each.

G. Judging the future by the past few years, it does not seem an irrational assumption—rather a low conservative estimate—to state that the material producers and the contractors alike have a definite outlook in the stabilized gravel or broken stone road during the next decade.

SYMPOSIUM ON INDUSTRIAL MINERALS

UNEXPLOITED OR LITTLE KNOWN INDUSTRIAL MINERALS OF ILLINOIS

By

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INTRODUCTION

Throughout the State of Illinois are scattered a variety of minor industrial minerals, most of which are unexploited and many of them not generally known. None of these resources as now understood are conceived to be the basis for an extensive mineral industry. However, some of them may be sources of additional revenue for certain of the State's mineral industries, which by reason of technical knowledge, geographic location, or business relations, are able to profitably exploit one or more of these resources.

The data presented are an accumulation of thoughts and observations rather than the results of an intensive study of the resources described. Probably some of the resources to be described and their utilization might well be made subjects of research by the Survey were not other projects of greater general significance and more widespread application occupying attention. Despite the fact that the data at hand are limited, it does seem worth while to point out these resources for the information and possible benefit of the Illinois mineral industry.

For many of the resources, those uses which have thus far come to mind will be suggested, likewise any significant test data at hand will be given. The field is, however, wide open to the ingenuity and resourcefulness of the Illinois mineral industry.

Due to the length and scope of this paper, details regarding many items have of necessity been omitted. Upon request the Survey will gladly furnish any specific data available, and will further be glad to cooperate in any way possible within its legitimate field with those of the Illinois mineral industries seeking to develop uses for these resources.

POTASH

The potash-bearing rocks of Illinois of possible commercial significance are of two major kinds, shales and greensands. In the latter the potash is probably present mainly as a part of the mineral glauconite, which is essentially a hydrous silicate of ferrous iron and potassium. The mineral is green in color, hence the name greensand for sands rich in glauconite.

Several articles have been published regarding potash in Illinois,¹ one of which deals with potash as a by-product from the shale used in cement manufacture. It is not proposed to consider this particular angle here, but rather to discuss potash-bearing rocks, with reference to their possible use as fertilizer, reviewing briefly the published data and adding recently obtained unpublished information.

SHALE

A potash-bearing shale, the Mountain Glen formation, 35-45 feet thick, outcrops at a number of places in Union County (fig. 8). Several deposits favorable with respect to quarrying conditions and railroad transportation have been described. This shale has an average K_2O content of $5\frac{1}{2}$ per cent and appears to be quite uniform with respect to potash content. Sixty-two per cent of the potash in a sample studied in detail was removable by extraction with sulfuric acid and pot culture tests indicate that the acid extractable material is largely responsible for the fertilizing value of the shale. A series of greenhouse pot culture tests were made in which various combinations of lime with kainit, alunit, leucite, and Mountain Glen shale were employed. The results of this work led to the following conclusions: "The pot culture work in the greenhouse indicates marked benefit to crops resulting from application of shale. The results are so striking and of such possible economic development as to warrant more extended investigations, particularly in the field. It is quite evident that the potassium in this shale can be directly used by crops in pot cultures under greenhouse conditions."² No commercial exploitation of this shale has occurred to date.

GREENSAND

Deposits of greensand have been observed in the vicinity of Olmsted³ (fig. 8) in southern Illinois. The exact thickness of the deposits is not known, but a 4-foot greensand bed separated from another $3\frac{1}{2}$ -foot bed of greensand by 1 foot of conglomerate has been reported to outcrop in sec. 13, T. 15 S.,

¹ Parr, S. W., Austin, M., Krey, F., and Stewart, R., Univ. Illinois Agr. Expt. Sta. Bull. 232, 1921.

Schroyer, C. R., Notes on potash possibilities in Illinois: Illinois Geol. Survey Bull. 38, pp. 434-436, 1922.

Schroyer, C. R., Potash as a by-product in cement manufacture: Illinois Geol. Survey Bull. 38, pp. 437-440, 1922.

² Parr, S. W., et al., Univ. Illinois Agr. Expt. Sta. Bull. 232, 1921.

³ Schroyer, C. R., Notes on potash possibilities in Illinois: Illinois Geol. Survey Bull. 38, pp. 434-436, 1922.

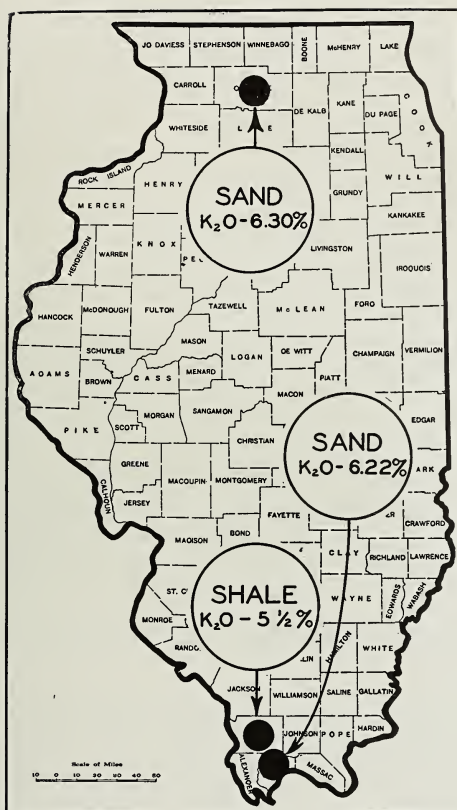


FIGURE 8.—Potash shale and greensand deposits in Illinois.

R. 1 E. This deposit analyzed 6.22 per cent K_2O , most of which probably was present as a constituent of the mineral glauconite. Detailed search may reveal other deposits of greensand in southern Illinois of sufficient size and having thin enough overburden to be workable on a moderate scale, but in general a thick, unconsolidated overburden is likely to be found on most deposits.

About one-half mile northeast of Oregon, Illinois (fig. 8), in the S. $1\frac{1}{2}$ N. $1\frac{1}{2}$ E. $1\frac{1}{2}$ sec. 3, T. 23 N., R. 10 E., there is exposed in what appears to be an old quarry a glauconite sandstone known as the Mazomanie formation. This is the only outcrop of this formation in Illinois, and it appears to have resulted from sharp folding or faulting of the bedrock or possibly both. Ten feet of the sandstone is exposed, but its total thickness is probably much greater than this. It is a fine-grained, brown, thin-bedded sandstone that is easily reduced to a sand. A count of 1,000 grains of the sand after washing to remove clay, showed 12 per cent of glauconite grains. A chemical

analysis of the raw sandstone reported 6.30 per cent K_2O . The amount of sandstone which could be quarried by open pit methods is probably small, but as the sandstone is overlain by a dolomite formation, a good roof probably would be available for underground mining. The possible effects of structural conditions on such a procedure would require thorough investigation.

The Glenwood sandstone, which also outcrops at many places near Oregon and lies above the thick St. Peter sandstone formation of that region, is likewise glauconite in places. No deposits have been reported which have a glauconite content comparable to that of the other greensands described, but careful search might reveal such deposits.

Probably the best known greensand deposits in the United States are those occurring in New Jersey. The K_2O content of these sands varies between 5 and 7 per cent.⁴ Attempts have been made to extract the potash from the New Jersey deposits, but so far as is known were unsuccessful commercially. However, the possible use of raw greensand as a potash fertilizer material⁵ should not be overlooked. It is reported⁶ that New Jersey greensand is spread on the soil in its raw state as a fertilizer and that Virginia greensand is dried and ground for use in commercial fertilizers.

COARSE-GRAINED AND FINE-GRAINED SANDS

Sands of various types are widespread throughout Illinois. In the northern part of the State glacial or related sands, most of them calcareous, are abundant and in this area likewise occur the unexcelled silica sands of the St. Peter formation. Sand is also abundant along Mississippi, Illinois and Wabash rivers and adjacent areas; some of it is calcareous, most of it is not high silica sand. In Alexander, Pulaski and Massac counties of extreme southern Illinois, sands of an entirely different age than those mentioned are to be found in deposits of considerable thickness and extent. Mostly the sands are medium or fine grained but in Alexander County coarse sand is also present. In view of the possible commercial significance of these coarse sands and very fine sands, a brief discussion of the Alexander County sands is given.

DESCRIPTION OF DEPOSITS

Near the center of the south line, SW. $\frac{1}{4}$ sec. 22, T. 15 S., R. 3 W., near Thebes, 16 feet of coarse sand is exposed in a hillside behind a farmhouse. Below the sand lies 16 feet of interbedded fine sand and clay and above it a variable thickness of brown clayey silt. There is a thin layer of chert gravel about 12 feet from the top of the sand deposit. The sand is red in color due to a coating of red clay on the grains. When washed free

⁴ Schroyer, C. R., *Idem*, p. 436.

⁵ Ladoo, R. B., *Non-metallic Minerals*, p. 444, 1925.

⁶ Ries, H., *Economic Geology*, p. 279, 1930.

of the clay about 5 per cent of the sand grains are seen to be chert and the remaining 95 per cent are almost entirely quartz. Some of the quartz grains are clear and transparent, others are of the milky variety. The shapes of the grains vary from angular to rounded and all grains exhibit more or less polished surfaces. Sample 61, table 1, was taken from this deposit, which is about $1\frac{1}{2}$ miles by road from two railroads and the Mississippi River.

Another deposit of a roughly similar nature occurs on the top of a ridge in SE. $\frac{1}{4}$ sec. 27, T. 15 S., R. 3 W. near Fayville. Seventeen feet of coarse red sand is exposed in an old gravel pit. Overburden is chert gravel and clayey silt but the nature of the exposure did not permit worth-while estimates of overburden thickness. Sample 42 was taken from the upper 6 feet of the exposure and sample 42A represents the entire 17 feet of sand (table 1).

Fine-grained, high silica sand is exposed at a number of places near Fayville, one of the best of which occurs in an abandoned man-made roadway cut between two valleys in the NW. cor. NE. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 34, T. 15 S., R. 3 W., where 35 feet of white micaceous sand locally containing thin beds of clay is exposed beneath about 25 feet of brown clayey silt. The deposit is about $\frac{1}{2}$ mile from two railroads and Mississippi River. Sample 300 was taken from the sand.

Twenty feet of similar white sand is exposed along the wagon road in the cen. SE. $\frac{1}{4}$ of the same section and sample 41 represents this deposit. The deposit is located along a railroad and is only a short distance from Mississippi River.

TABLE 1—RESULTS OF SIEVE TESTS ON ALEXANDER COUNTY SANDS
(The sieve test of St. Peter sand from the Ottawa district is included for comparison.)

Sieves	Coarse sands			St. Peter sand	Fine sands	
	No. 42A	No. 42	No. 61		No. 41	No. 300
—4 + 6 mesh.....	1.1	0.5	0.0	.....	.....	.....
—6 + 10 mesh.....	3.1	3.0	2.3	0.0	.....	.....
—10 + 20 mesh.....	19.8	27.0	32.3	0.4	.....	.....
—20 + 28 mesh.....	29.9	26.0	31.3	18.3	0.0	.....
—28 + 35 mesh.....	19.9	16.4	15.7	52.5	0.1	.....
—35 + 48 mesh.....	8.7	12.1	4.3	19.2	0.5	0.0
—48 + 65 mesh.....	4.1	4.0	2.6	4.9	3.9	2.0
—65 + 100 mesh.....	2.2	1.9	1.5	2.7	57.1	17.6
—100 + 150 mesh.....	0.3	0.2	0.2	1.2	21.7	20.4
—150 + 200 mesh.....	.....	.....	.....	0.5	8.8	34.4
—200 + 270 mesh.....	.....	.....	.....	0.1	1.9	11.6
Pan.....	0.2	0.2	0.3	0.1	0.6	9.8
Clay.....	10.5	8.5	9.6	0.6	4.7	4.2

USES OF SAND

Laboratory washing tests on the coarse sand shows that most of the clay associated with it is removable without difficulty giving rise to a light pinkish-colored sand. It would seem likely, therefore, that a commercial washing process, such as that used in the Ottawa district, would yield a product suitable for some of the physical uses of silica sand. However, it is doubtful if simple washing would yield a product suitable for most chemical uses of silica sand. The outstanding character of the sand is its coarseness, its non-calcareous nature and high silica content. So far as is known, the sands described are the coarsest quartz sands in Illinois. Compared with a sample of silica sand from Ottawa it is seen that whereas the Ottawa sand contains 0.4 per cent material coarser than a 20-mesh sieve, the southern Illinois sands have 24, 30, and 35 per cent plus 20-mesh material. Likewise, a figure of 19 per cent coarser than 28 mesh for the Ottawa sand is to be compared with figures of 54, 57 and 66 per cent for the southern Illinois sands. Figure 9 presents some of these data graphically.

While further testing is necessary before specific uses can be recommended, it is suggested that the sand is worthy of consideration for sand blast sand, filter sand, and probably other uses. Whether the deposits are of suitable character and of sufficient size to warrant commercial exploitation cannot be stated on the basis of the data available from the natural outcrops; however, it is believed the chances are good that detailed exploration will reveal commercial deposits.

The fine-grained sands are composed, exclusive of their clay content, of about 96 per cent quartz, 3 per cent white mica, and 1 per cent other minerals. Laboratory washing gives rise to a white sand except for small amounts of yellow iron-cemented clay grains. Probably scalping over a 65-mesh sieve would remove most of the clay pellets and one-third of the mica. Washing also offers an opportunity to eliminate clay and a considerable portion of the mica. The latter may be marketable.

Sieve tests on two samples of the fine-grained sand are given in table 1, which shows, excluding clay, 33 per cent finer than 100 mesh for one sample and 76 per cent for the other.

The fine-grained sands may have a number of uses but the only one which has been investigated thus far is molding sand. Results of a molding sand test made in the Foundry Laboratory, University of Illinois, are as follows:

Am. Foundry Men's Assn. Grain fineness No. — 20

Cohesive strength—100

Permeability—38

This sand is very good in fineness, permeability and refractory qualities, but the bond or cohesive strength is low. The bonding material is also short lived. As found in nature the sand would have a small use in core sand mixtures; if the cohesive strength were raised by adding about 2 per cent of plastic clay, it could be used for heavy brass castings.

If the sand were treated to remove mica and clay and then were used with an artificial bond, it would be a good molding sand for brass, aluminum and small cast iron castings and also a good core sand for general purposes.

The statement previously made regarding commercial deposits of coarse sand applies as well to the fine-grained sands.

PEAT

The peat deposits of Illinois occur mainly in the north half of the State and in Tazewell and Mason counties in the central part. Although the peat resources of Illinois have not been studied in detail, it has been estimated that in the 6 counties thought to contain the largest deposit of peat—DuPage, Kane, Kankakee, Lake, Tazewell and Winnebago—over 42,000 acres of peat are present which would yield about 10,000,000 short tons of air dried peat.⁷ In general most of the deposits are comparatively small but a deposit in Cattail Slough near Sollers in Whiteside County is estimated to contain nearly 4 million tons of air dried peat, a deposit near Manito in Tazewell County, 120,000 tons, and a deposit near Antioch in Lake County over 400,000 tons.⁷

The thickness of the peat deposits usually ranges between 5 and 20 feet but deposits as thick as 35 feet are reported. Most of the peats are the result of the decay of grass, sedge or cattail vegetation. No sphagnum moss peat of consequence is known.

Analyses of Illinois peat⁸ indicate that in general they contain too much ash to be used as fuel, though they may be used in making fertilizer and packing material. The Illinois peats are in the main relatively impure, however, the average nitrogen content of 18 samples of Illinois peat is 2.65 per cent which is above the general average. Five Illinois samples contained over 3 per cent nitrogen and one from Lake County 3.84 per cent, an unusually high figure for raw peat.

Comparatively small amounts of peat or muck are now being produced in the Chicago district. One of their important uses is lawn dressing. At Manito peat was once produced in considerable amounts as a filler or packing material and for other purposes.

The effectiveness of raw Illinois peat in general as a fertilizer has not been definitely determined but due to its water holding capacity, the peat can be used advantageously for reducing cracking and improving the texture of heavy clay soils. Packing material, filler, litter, lawn dressing and for addition to the soil on greenhouse benches are other possible uses of Illinois peats.

⁷ Soper, E. K., and Osbon, C. C., The occurrence and uses of peat in the United States, U. S. Geol. Survey Bull. 728, pp. 104, 107, 109, 110, 1922.

⁸ Ibid., pp. 27 and 58.

MARL

The term marl is popularly used in Illinois to describe any incoherent deposits consisting principally of CaCO_3 . Shell marl is one general type of material to which the term is applied and it is likewise used to describe spring deposits. Materials of the latter type have been observed at several places in Calhoun County, in Bureau County, in Fairies Park at Elgin and other places north of the park on the east side of Fox River valley, and near Danville. In general these deposits are small and solely of local significance as sources of material mostly used as agricultural limestone.

The shell marl deposits on the contrary in places may reach considerable size. They are composed of the shells of small fresh water animals together with variable amounts of clay and sand. In general the shell marl deposits lie below peat deposits, although in some deposits the peat is thin. Discovery of the deposits is mainly a matter of chance or of prospecting peat deposits or swampy depressions. In general the marl accumulated in ancient lakes which existed in depressions which are usually still reflected in the present topography and topographic conditions favoring relatively clear quiet lakes might be expected to favor the formation of marl. It is believed that the northern third of the State is more favorable for marl deposits than the southern two-thirds, and that in general marl deposits will be found most commonly in Lake, McHenry, Cook, DuPage and Kane counties.⁹

A brief description of some of the larger known deposits may be of interest. Southwest of Chatsworth in Livingston County a marl deposit is reported¹⁰ to be 40 feet deep and to cover 40 acres. Another deposit near DesPlaines on the Elmhurst Road just north of McDonald Road is said¹¹ to be 19 feet deep and some 16 acres in extent. A deposit in Phillips Park in Aurora was shown by borings to have a maximum thickness of 30 feet; other borings recorded thicknesses of 13, 16 and 18 feet.¹² A few miles west of Antioch in a bog between channel Lake and Lake Marie in the flood plain of Fox River 6 to 8 feet of marl was encountered in the center N. $\frac{1}{2}$ sec. 3, T. 43 N., R. 9 E.; about 6 miles north of Barrington, 6 to 8 feet of very pure marl overlain by roughly 1 foot of less pure marl is reported; and Lilly Lake south of the town of the same name contains about 20 feet of peaty marl.¹³ Further and more specific information regarding marl in Lake and McHenry counties is expected to result from a study of the geology and mineral resources now in progress.

The composition of Illinois shell marls is not known in detail but it seems likely the marls containing over 85 or 90 per cent carbonates may be reasonably common.

⁹ Ekblaw, G. E., Personal communication.

¹⁰ Pontiac, Ill., "Leader," July 16, 1937.

¹¹ DesPlaines, Ill., "Times," Aug. 6, 1937.

¹² Powers, Wm. E., Geological setting of the Aurora mastodon remains: Trans. Illinois Acad. Sci., vol. 28, no. 2, p. 194, December, 1935.

¹³ Ekblaw, G. E., Personal communication.

Because shell marl is usually easy to dig and requires little if any crushing, it is attractive for the production of agricultural limestone.

SLATE

There are no true slates in Illinois, but there are several types of material to which this term is sometimes popularly applied and it is these which will be discussed briefly. The first and most widespread "slate" is the variety associated with the coal beds of the State, and sometimes called "roof slate." These "slates" in places lie immediately above a coal bed or several feet of other strata may intervene between the top of the coal and the "slate". They are usually black due to a comparatively high carbon content, fine grained, well bedded and break into brittle, thin sheets sometimes of considerable size. They resemble true slate somewhat in appearance and cleavage, but do not have the hardness or weather resistance of true slates. None of the "slates" tested thus far have been calcareous, but many of them contain pyrite, though this is not necessarily a general characteristic.

As has been intimated, the Illinois black "slates" are of Coal Measures age and as many Illinois coals have some "slate" above them, it is evident that the "slates" are widespread. It is impossible to describe all the known Coal Measures "slate" outcrops in Illinois, but a few data will serve to give an idea of their occurrence and thickness. In northern Illinois, the LaSalle No. 2 coal has 2 to 3 feet of black "slate" above it in that part of the area lying west of Starved Rock State Park; east of this place the "slate" is lacking, or inconsequential. Also, in northern Illinois the Springfield No. 5 coal is overlain generally by 2 to 3 feet of "slate." A similar thickness of "slate" lies below the LaSalle limestone in the same general area and likewise 2 to 3 feet of "slate" occurs below the No. 6 coal of the Streator area and is the floor of coal mines.

Four feet of black "slate" is found in places over No. 1 coal north of Monmouth in western Illinois. "Slate" also occurs above the No. 2 coal of western Illinois. In the vicinity of Peoria and Galesburg the No. 5 coal has a "slate" which reaches 4 feet thick.

In Williamson County of southern Illinois the No. 5 coal also has a black "slate" above it in places. The "slate" has a maximum thickness of about 3 feet. Many mines in No. 6 coal in southwestern Illinois locally have 2 to 3 feet of "slate" above the coal.¹⁴

No special study has been made of Coal Measures "slate" deposits capable of being worked solely as a source of slate. Some such deposits probably exist, but an easier and probably cheaper procedure would be to produce "slate" in conjunction with coal mining.

¹⁴ Cady, G. H., Personal communication.

Two other types of slaty shales occur in southern Illinois a few miles southwest of Jonesboro in Union County. One of these is a black or dark brown well bedded shale which splits into thin sheets and the other is a highly silicified, hard shale. Both occur in accessible deposits up to 35 feet thick. The black shale owes its color to carbonaceous matter and is usually not calcareous. The silicified shale is hard, brittle and slaty in appearance, gray to greenish gray in color, and in places is slightly calcareous, but considerable thicknesses of noncalcareous shale are present.

So far as is known no use has been made of the Coal Measures "slates" except as a road material. The black southern Illinois shale is not known to have been used for any purpose, but the silicified shale was at one time quarried and crushed for roofing granules. Its weather resistance is reported to have been unsatisfactory, however, and production was abandoned.

No comprehensive investigation of the above mentioned materials as mineral fillers, particularly as a substitute for slate flour, has been attempted but it appears that such a study might have possibilities. Also worthy of consideration is the possibility that the southern Illinois silicified shale might provide a suitable granule for use in preparing coated roofing chips.

BRINES

At the present time salt (NaCl) is being produced in the Middle West from rock salt mines in Kansas, mines and brines in Michigan and from brines in Ohio. It is not generally known, however, that during the nineteenth century Illinois was an important salt producing state; in fact, for a time the major producer in the Middle West. Salt works existed at Equality, Central City, Murphysboro, St. John, Danville, and probably at other places. The eventual cessation of salt production in Illinois was due to the discovery of stronger brines elsewhere in the Middle West.

The fact that salt making from the relatively weak brines used in Illinois in the nineteenth century could not compete with the production of salt from stronger brines elsewhere should not be interpreted to mean that Illinois does not have brines worthy of consideration. As a matter of fact, it has been only in recent years that any even moderately detailed data regarding Illinois brines have been available. There are now in the Survey files about 300 analyses of Illinois brines, most of which were obtained from oil wells or wells drilled for oil. So far as is known no special search for strong brines has been made in Illinois, so that our knowledge of Illinois brines is really a by-product of information obtained for purposes of the oil industry. Nevertheless, an examination of these data shows much of interest.

TABLE 2.—ANALYSES OF BRINES FROM ILLINOIS AND OTHER STATES
(Hypothetical combinations in parts per million)

1	2	3	4	5	6	7	8	9	10	11	12	13
KNO ₃	5	2	1	2	3							
KCl.....	5,525	6,520	1,493	9,322	709					713		
NaNO ₃	115,200	68,950	10,770	91,980	30,150	91,595	42,582	87,889	84,300	310,977	234,050	141,000
NaCl.....	854	123	35	138		27	9	4				
MgCl ₂	10,070	8,468	20,360	5,055		3,695	3,900	4,414	5,590	462	21,200	31,000
CaCl ₂	35,620	4,643	400	8,166		3,024	125,382	9,400	14,340	1,033	32,900	83,000
CaSO ₄	1,212	7,752	393	3,288	2,375	796	886	280		4,857	800	
CaCO ₃	64	52	467	236	227	71	146	103				
SiO ₂	132	7	19	18	19	160	220	120	12			
Fe ₂ O ₃	11	11			17	17	143	324	83	0		Trace
Al ₂ O ₃	16	40	24	22	9	140	1,380	240		0	50	Trace
MnO.....	1				1	5	15	5				
Na ₂ SO ₄					6,649							
(NH ₄) ₂ SO ₄					43							
MgSO ₄					1,069							
Non-vol.....	67		35		29	100	180	80				
Total.....	167,918	117,111	33,997	118,227	41,300	99,641	6174,869	6102,869	6105,198	6318,163	289,000	6256,000

a Includes Ca(NO₃)₂-11 parts per million.

b Includes Ca(NO₃)₂-26 parts per million.

c Includes Ca(NO₃)₂-10 parts per million.

d Includes MgBr₂-155 parts per million; SrCl₂-257 parts per million; BaCl₂-343 parts per million; NaI-4 parts per million and Li₂O-trace.

e Includes MgBr₂-12 parts per million; SrCl₂-89 parts per million and Li₂O-trace.

f Includes bromine-1000+ parts per million.

1. St. Peter sandstone; J. R. Middagh well, near Lawrenceville, Lawrence County, Illinois; depth 5,185 feet. No oil associated with this brine.
2. Carper sandstone, Lower Mississippian; S. McClelland well No. 1, near Martinsville, Clark County, Illinois; depth 1,400; oil well.
3. Carlyle sand, Devonian; M. Smith; near Carlyle, Clinton County, Illinois; depth 2,620; oil well.
4. Biehl sand, Lower Pennsylvanian; Price No. 2, near Alledale, Wabash County, Illinois; depth 1,480; oil well.
5. Carper sandstone, Lower Mississippian; S. McClelland well No. 2, near Martinsville, Clark County, Illinois; depth about 1,400 feet; oil well.
6. Biehl sand, Lower Pennsylvanian; Widmer Oil Company, well No. 4, near Alledale, Wabash County, Illinois; depth 1,210; dry hole.
7. "McClosky sand," Ste. Genevieve formation, Lower Mississippian; D. Smith, well No. 7, near Clay City, Clay County, Illinois; depth 2,633 to 2,648 feet; oil well.
8. "McClosky sand," Ste. Genevieve formation, Lower Mississippian; Arbutnot No. 3 well, near Noble, Richland County, Illinois; depth about 2,950 feet; oil well.
9. Penolst sand, Bethel formation, Upper Mississippian; Merryman No. 1 well; depth 1,391 to 1,418 feet; oil well.
10. Coal Ridge Salt Works, Pomeroy, Ohio; Conemaugh formation (Pennsylvanian). Ohio Geol. Survey Bull. 8, p. 27, 1906.
11. Artificial brine, Cleveland, Ohio, H. Ries, "Economic Geology," 1930, p. 222.
12. North American Chemical Co., Bay City, Michigan, Depth 970 feet; upper Marshall sandstone (Mississippian). Michigan Geol. and Biol. Survey Pub. 15, Ser. 12, p. 59, 1914.
13. Midland Chemical Co., Midland, Michigan, Depth about 1,300 feet; upper Marshall sandstone (Mississippian). Michigan Geol. and Biol. Survey Pub. 15, Ser. 12, p. 59, 1914.

Table 2, analyses 1 to 9, shows the composition of some of the stronger Illinois brines. Analysis 1 is the highest on record in NaCl and second highest in CaCl_2 ; No. 2 is the highest in CaSO_4 ; No. 3 is the third highest in CaCl_2 ; No. 4 is the highest in MgCl_2 ; No. 5 is the highest in KCl and also quite high in CaCl_2 ; No. 6 is the highest in NaSO_4 ; No. 7 from the new Clay City oil field is quite high in NaCl; No. 8 from the new Noble oil field has the highest recorded CaCl_2 content; and No. 9 from the new Patoka oil field is moderately high in NaCl. Samples 10 and 11 are brines from Ohio and 12 and 13 are from Michigan.

In general, it is believed that the most important constituents of the brines under discussion are NaCl, CaCl_2 , MgCl_2 and bromine. The Michigan and Ohio brines contain bromine; in general, most of the Illinois brines thus far examined contain very little, if any, bromine,¹⁵ though one analysis showed 78 p.p.m. of NaBr according to hypothetical calculations. No intensive search for bromine-bearing brines has been made in this State, however, so that the data at hand are not conclusive.

Disregarding bromine content, it is interesting to compare some of the Illinois brines with the out-of-state brines reported in table 2. Sample No. 8 which is an artificial brine presumably produced by pumping water into and then out of a salt bed, is not fairly included in the comparison. As figure 10 shows, Illinois brines compare fairly well with the other brines. The outstanding brine is No. 1 which comes from the St. Peter formation in Lawrence County at a depth almost 5200 feet. Unfortunately no data regarding the quantity of brines available from Illinois wells is available but there is reason to believe that an adequate quantity may be expected at least from certain formations.

Illinois is at present experiencing a new oil boom which is accompanied by the drilling of numerous wells in regions where no wells or only a few wells previously existed. Unexplored water-bearing strata will be tapped, probably the St. Peter formation mentioned above will be penetrated at a number of places. Insofar as it is possible, the Survey will continue its brine sampling and analysis, with the hope that even stronger brines than any thus far known will be discovered. In the meantime the data at hand is worthy of thought and attention, particularly in its relation to the possible success of a special search for stronger brines in Illinois.

GYPSUM AND ANHYDRITE

Gypsum and anhydrite are two minerals which are closely akin in chemical composition, the difference being that gypsum is calcium sulphate plus two molecules of water, whereas anhydrite is calcium sulphate without chemically combined water. The water which the gypsum contains can be

¹⁵ Rees, O. W., Personal communication.

driven off by proper heating and the burned material when wetted again takes up water to give a compound having the original gypsum composition. This last is the familiar action which occurs in the setting of plaster of paris.

Anhydrite, since it contains no moisture, does not possess the properties of gypsum just described. Consequently it has not been a widely used mineral. Due, however, to the fact that it is often found in large amounts associated with gypsum, a considerable amount of research has been devoted to a search for major uses for this material, particularly in the field of building materials. Successful research in England resulting in the commercial manufacture of a finish coat plaster, partition tile and "fine aggregate walling" has been reported recently.¹⁶ Further research may soon broaden considerably the field of usefulness of anhydrite.

The existence of deposits of gypsum and anhydrite in Illinois is not generally known; however, considerable thicknesses of these materials are present in places in the area shown in figure 12. The minerals occur in the upper part of the St. Louis formation at depths of 700 to 1,200 feet or less. Unfortunately most of the data regarding gypsum and anhydrite comes from churn drill records which do not permit accurate evaluation of thicknesses. However, several diamond drill cores are available which give a clew as to the probable nature of the gypsum and anhydrite deposits. The results of a study of one of these cores are given in figure 13. The commingling of gypsum, anhydrite and limestone in various proportions which characterize all the cores available is well illustrated. It is to be noted that 4 mineralized zones were encountered between 943 and 1,015 feet in depth and that 28 feet of core contained gypsum and/or anhydrite.

Iowa, Kansas, Michigan and Ohio are all important Middle Western gypsum-producing states and the deposits from which the gypsum is obtained are generally at the surface or not much more than 100 feet below the surface. Whether or not it would be possible to produce gypsum and anhydrite from Illinois deposits on a commercially competitive basis cannot be determined from the data at hand. However, it does appear worth while to indicate the existence of the Illinois deposits and the possibility that the gypsum and anhydrite horizon in the St. Louis formation may be found by careful prospecting at a relatively shallow depth in the southwest part of the area shown in figure 12.

WAX- OR RESIN-BEARING LIMESTONE

In Calhoun County (fig. 11) there outcrops a stratum of wax-or resin-bearing limestone which so far as is known is not duplicated elsewhere in the State. The deposit is probably a part of the Decorah formation and under-

¹⁶ MacTaggart, E. F., Gypsum anhydrite as a base for plaster products: *Rock Products*, vol. 40, no. 7, pp. 46-48, July, 1937.

lies the Kimmswick formation which is a high calcium limestone. It may be the stratigraphic equivalent of the "oil rock" of the Illinois-Wisconsin lead and zinc area.¹⁷ The extent of the wax- or resin-bearing limestone bed has not been determined but it appears likely that it underlies a considerable area. An exposure in the NE. $\frac{1}{4}$ SE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 6, T. 12 S., R. 2 W., shows 7 feet of the limestone and this represents only a part of the total thickness of the bed as the bottom of the stratum was covered by stream deposits.

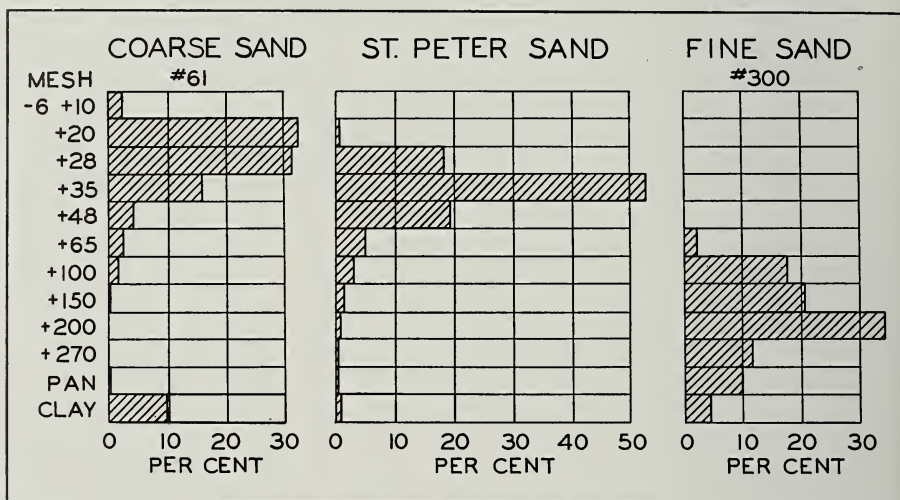


FIGURE 9.—Mechanical composition of a coarse sand and a fine sand from southern Illinois in contrast with a sample of St. Peter sand from the Ottawa district.

The limestone is a chocolate brown but weathers a light gray or almost white. It occurs in beds 3 to 6 inches thick and thin partings of shale are present between some of the limestone beds. This shale will burn when ignited with a match. A chemical analysis of a sample of the limestone is shown in figure 11. These data indicate that the limestone is somewhat impure, the chief impurity being silica, and that it is low in Fe_2O_3 . The combustible carbon figure results from the wax or resin present.

The wax or resin occurs mostly as irregular, brownish-yellow masses disseminated through the limestone. A few brownish colored particles having definite outlines are also present and may be plant remains.

It is estimated that the combustible carbon figure shown in the chemical analysis is equivalent to a value of about 500 B. t. u. per pound of limestone.

¹⁷ Bain, H. F., Zinc and lead deposits of the upper Mississippi Valley: U. S. Geol. Survey Bull. 294, pp. 25-27, 1906.

Trowbridge, A. C., and Shaw, E. W., Geology and geography of the Galena and Elizabeth quadrangles: Illinois Geol. Survey Bull. 26, p. 47, 1916.

A ton of the limestone would, therefore, contain about 1,000,000 B. t. u. which is equivalent to the B. t. u. in about 80 pounds of good Illinois coal.

The chemical composition of this limestone compares favorably with some natural cement rocks which have been used for making natural cement, though many of the limestones so used are higher in silica and alumina. Whether the rock can be used for making natural cement or some other similar product has not been investigated but the unique combination of low iron content and the wax or resin fuel is of interest. Probably the presence of wax or resin alone is sufficient to justify description of the limestone; the possibilities for the recovery of this wax or resin may bear study.

The deposit is located about $11\frac{1}{2}$ miles from Mississippi River and about the same distance from a power transmission line. No rail transportation is available. Conditions for underground mining appear to be good.

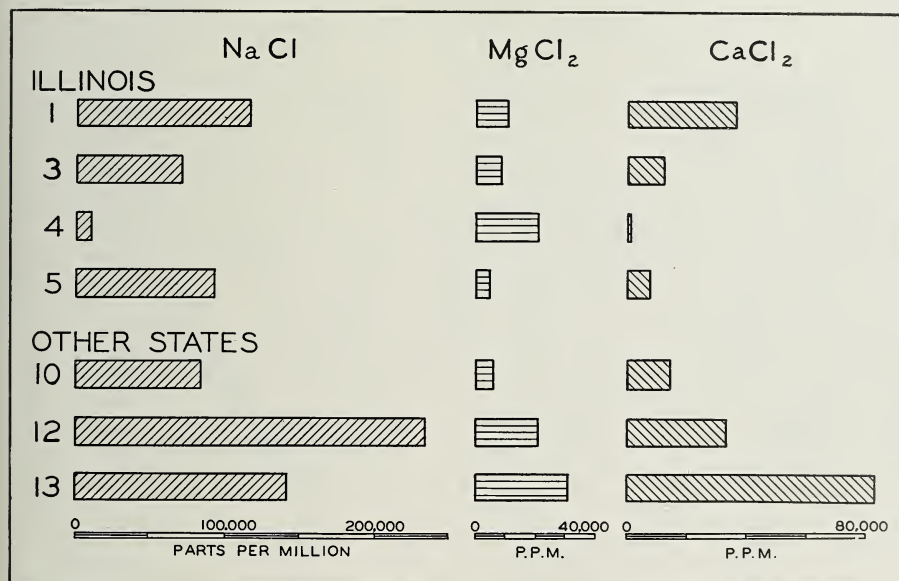


FIGURE 10.—Comparison of Illinois brines with those from other states. Data in parts per million (see table 1).

QUARTZITIC SANDSTONE

In two localities of extreme southern Illinois, there occur deposits of sandstone whose grains are firmly cemented by quartz. In a sense they are quartzites but since the degree of cementation is not as firm as that of the Minnesota and Wisconsin quartzites familiar in the Middle West, the term quartzitic sandstone is used.

About 6 miles below Golconda in the bluffs of Ohio River in the NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 13, T. 14 S., R. 6 E., Pope County, there is exposed 30 feet of sandstone, most of it quartzitic, which is a part of the Bethel formation. The total thickness of the quartzitic sandstone may be considerably more than 30 feet. The sandstone layers vary from an inch to 8 inches or more thick and many of them are separated by shale partings. These partings facilitate the quarrying of blocks or slabs. The sandstone is light brown or gray in color and contains small brown iron-stained spots. Some layers of clayey sandstone are present. The deposit is located on Ohio River but is not near any railroad. Quarrying conditions are favorable for the production of large amounts of sandstone.

Another quartzitic sandstone outcrops in Rineking Hill cut along the Southern Illinois and Kentucky Railroad near the village of Round Knob,

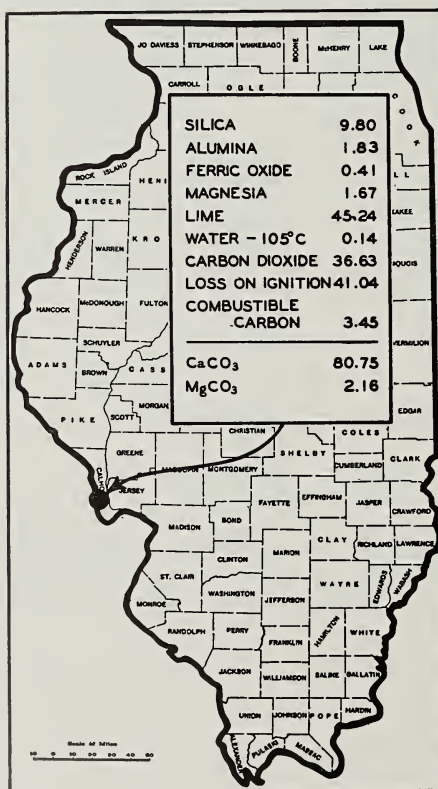


FIGURE 11.

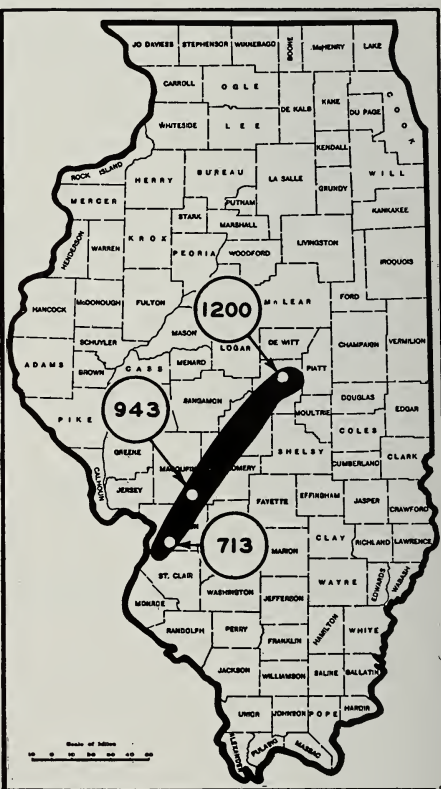


FIGURE 12.

FIGURE 11.—Location and chemical composition of wax or resin-bearing limestone.

FIGURE 12.—Area of gypsiferous St. Louis formation in central and southern Illinois. The numbers indicate the depth to the gypsum horizon. Data furnished by L. E. Workman.

Massac County in the E. $\frac{1}{2}$ NE. $\frac{1}{4}$ sec. 23, T. 14 S., R. 4 E. About 15 feet of white to gray quartzitic sandstone is exposed. It occurs in beds 1 to 6 inches or more thick. The deposit shows considerable folding and thorough prospecting is necessary to determine whether sufficient sandstone is available under a reasonable amount of overburden to warrant possible exploitation. Overburden is unconsolidated sand and clay.

No tests have been made on the last mentioned sandstone but the Pope County sandstone gave results in preliminary tests which suggest it may have use in making silica brick although crushing produced a higher per cent of fines than in the case of Minnesota quartzites. The sandstone would probably make a good decorative flagstone and tests indicate that it will withstand temperatures of 3000° F. without fusion. It may, therefore, be useful as firestone for foundry cupolas and for lining pickling vats in the metallurgical industry. Some of the sandstone has been used for riprap along Ohio River. Possibly the Massac County sandstone and likewise a number of other Illinois sandstones may also be suitable for some of the same purposes.

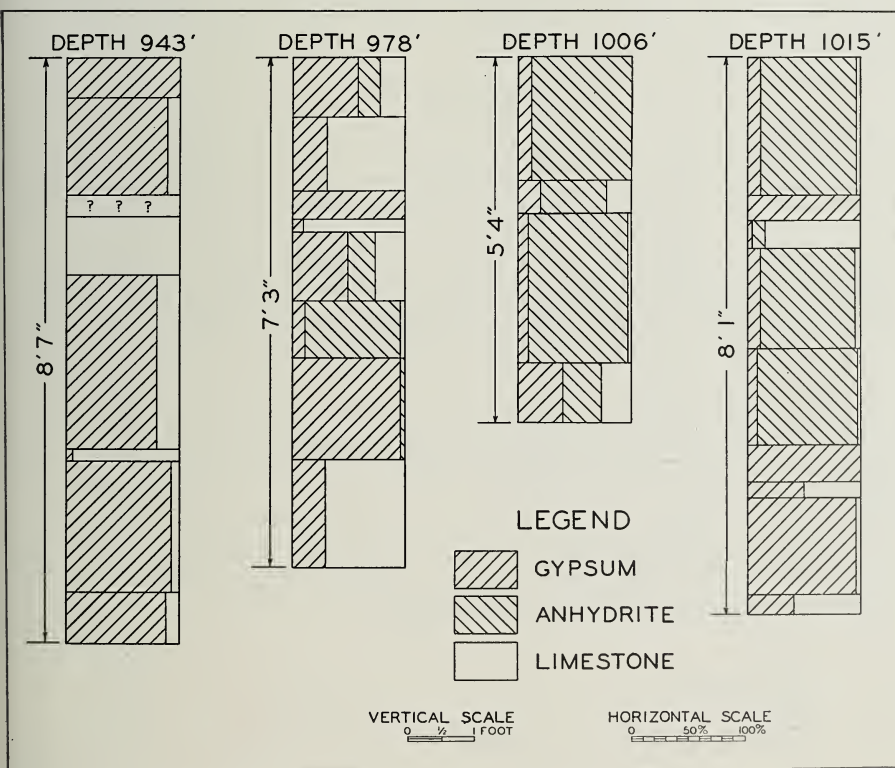


FIGURE 13.—Distribution, depth, thickness, and estimated relative percentages of gypsum, anhydrite, and limestone in core of well located in southeastern Macoupin County.

COLORED CLAYS AND SANDS

Colored sands and shales are quite widespread throughout the State and deposits occur in such number and diversity that no attempt will be made to discuss their distribution. It does seem worthwhile, however, to present a few observations regarding them. Red shales and clays occur at a number of places, maroon clays are known, a deposit of purple shale has been observed and likewise deposits of green clay and shale and brown clay and shale. Some of these clays and shales particularly the reds, are rather strongly colored and consideration is warranted of their possibilities as low grade pigments, particularly for mortars and concrete. Investigation of their value as colored fillers may also be worth while.

Brown and yellow sands, and more rarely orange and red sands occur in many parts of Illinois. Some of them burn red. Most of them are moderately high in clay and their color is due to iron oxides. The question is raised whether they may not have value as a coloring material to be used as a part of the fine aggregate for mortar and concrete. Likewise, the fact that many of them burn an attractive color suggests that they may be of value for sanding or veneering brick.

LIMONITE

Although it is not generally known, Illinois at one time had a flourishing iron-making industry which depended upon deposits of Illinois limonite for ore. Hardin County was the site of this industry and two furnaces were operated there. The limonite deposits resulted from the decay of limestone and other rocks and consisted of small pellets and larger irregular chunks scattered through clay and soil. The deepest accumulations of this kind are likely to be located on the sides of knobs or spurs and some of the old ore pits are said to have been 90 feet deep. "All the known occurrences of iron ore deposits in Hardin County are in areas underlain by the Fredonia or St. Louis limestones and in that particular they are like most of the extensive limonite deposits in eastern United States, as in Pennsylvania and Alabama."¹⁸

Usually the Hardin County limonite now visible is yellow, brown or red. No recent analyses have been made but an early report on the ore from the bank of one of the early furnaces is as follows:¹⁸

	<i>Per Cent</i>
Water	10.8
Siliceous earth	5.0
Fe ₂ O ₃	80.0
Alumina	3.7
Loss and alkalies not estimated.....	0.5
	<hr/> 100.0

¹⁸ Butts, Chas., *Geology of Hardin County: Illinois Geol. Survey Bull.* 41, p. 305, 1920.

There is probably a considerable quantity of limonite in Hardin County but the nature of the deposits makes estimates impossible without detailed and extensive exploration. The deposits lie about 3 to $3\frac{1}{2}$ miles northwest of Elizabethtown, which is located on Ohio River. No railroad is close at hand.

The limonite deposits of Hardin County are no longer important as sources of iron ore. It may be, however, that they could be used as a source of mineral pigment. The raw ground limonite is yellow brown in color, it can be burned red or maroon.

SIDERITE

The mineral siderite, which is ferrous carbonate, occurs in Illinois mainly as nodules or thin layers in the Coal Measures shales. The nodules are commonly disc shaped, varying in length from about 2 to 12 inches and are usually less than 4 inches thick. The beds are commonly less than 3 inches thick and are generally lenticular. The nodules or beds are mostly gray or dark gray on the inside and where they have been exposed to the weather have an exterior coating of brown or yellow hydrated iron oxide. They contain variable amounts of clay and some also contain calcium carbonate. The latter causes them to effervesce with cold hydrochloric acid. The term "clay iron-stone" concretions is often applied to the sideritic nodules.

No extensive investigation has been made of the chemical composition of the sideritic nodules but two samples showed respectively 31.3 per cent and 47.3 per cent Fe_2O_3 , which is equivalent roughly to 50 and 75 per cent ferrous carbonate.

The sideritic concretions and beds are comparatively common in a number of the thicker Coal Measures shale formations, especially in the basal 5 to 10 feet. They have been noted in the Canton, Purington, Farmington, and Francis Creek shales, which outcrop extensively in northern and western Illinois. No exact data are available regarding the quantity of these concretions present in the various shales but it is estimated that in places the sideritic materials constitute 5 per cent and possibly as much as 10 per cent of the shales.

It is not known that the Illinois sideritic concretions have any commercial value, however, their possible uses are not known to have been investigated.

SUMMARY

Illinois contains a variety of little used mineral resources which merit consideration. These include potash shale, greensand, coarse and fine sands, peat, marl, "slates" and slaty shales, brines, gypsum and anhydrite, wax or resin bearing limestone, quartzitic sandstone, colored clays and sands, iron ore, and siderite, but little is known in detail about most of these resources and their possible uses. Each of them might merit research as a part of the Survey's program were not other more important problems of wider interest and greater potential returns demanding attention. It seems worthwhile, however, to call the attention of the Illinois mineral industry to these minor resources so that benefit may accrue to any of the industries which by reason of technical knowledge, geographic location or business relations are able to advantageously exploit one or more of these resources.

MAGNETIC SEPARATORS AND THEIR POSSIBLE APPLICATIONS TO THE BENEFICIATION OF ILLINOIS INDUSTRIAL MINERALS

By

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Before going to the application of magnetic separators to Illinois minerals, I want to outline briefly the art of magnetic separation. In general, magnetic separation can be divided into four classifications.

The first and most common is the removal of tramp iron such as nuts, bolts, coupling pins, etc., from material going to crushers, pulverizers, grinding mills and similar equipment. Tramp iron passing into a grinding circuit causes considerable damage and often fires; and a magnetic separator properly applied prevents this. Some of the materials being so treated in Illinois includes coal, gypsum, fluorspar and many others. The most popular type of magnetic separator used for this application is the magnetic pulley, but where a magnetic pulley cannot be installed, a spout magnet which becomes part of the spout or chute, or a suspended magnet, may be installed with satisfactory results.

The second general classification is the removal of deleterious iron, such as scale, iron of abrasion, and other iron oxides, from materials which are so contaminated. For this application many standard and special type separators are available, and recent improvements in high intensity magnetic separators has widened this field considerably. Typical applications include the purification of glass sand, bauxite, fluorspar, clays and other minerals.

The third classification is the reclamation of materials. Occasionally the iron only is wanted, but more often two or more materials are mechanically combined and the mixture, as such, is practically valueless. After separation, however, the value of each separate material is increased considerably. The separation of ferrous and non-ferrous borings and turnings, the recovery of iron from foundry refuse, and the separation of iron from slag, are but a few examples of this application. The type of separator required is the medium intensity machine, and the size and style depends, of course, upon conditions.

The fourth classification is the concentration of minerals and ores, to raise the grade and eliminate the gangue. A typical application is the concentration of zinc and lead in the Galena, Illinois, district.

The zinc and lead ores there are the sulphides and they are associated with pyrite. Lead separates very readily from the zinc and the pyrite through the specific gravity method, jigs and tables, but the concentrates from the jigs or tables must be roasted so as to make the pyrite magnetic. When roasted the pyrite is readily separated from the zinc.

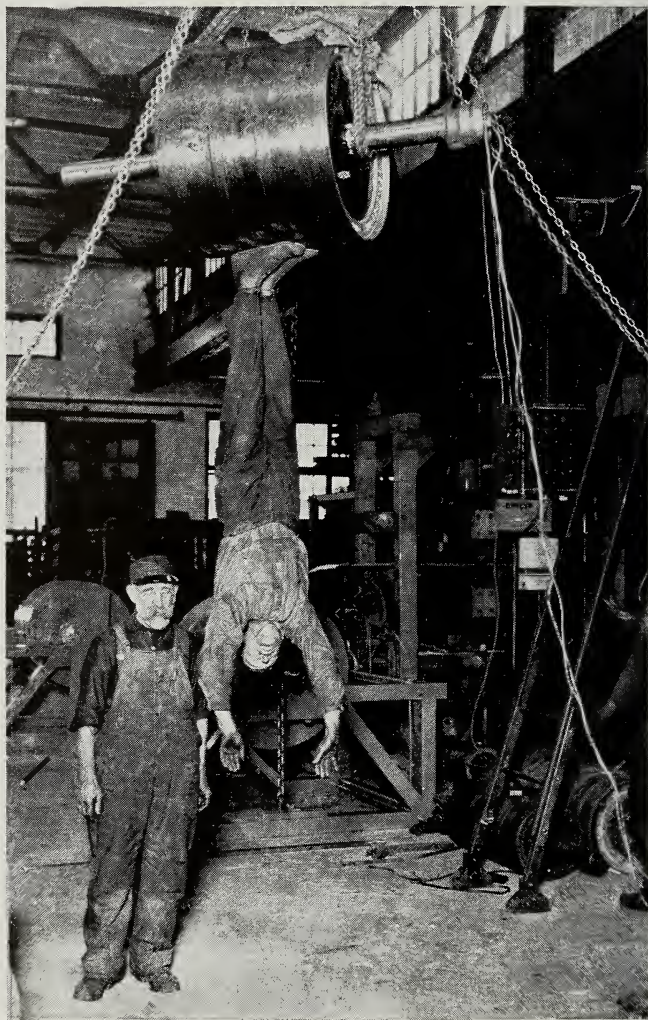


FIGURE 14.—The man being held suspended face downward by the attraction of the magnetism of the magnetic pulley for the iron in his shoes illustrates the tremendous strength of the high intensity magnetic pulley. This is a graphic illustration of the power that can be attained when the design incorporates the proper proportion of copper wire and dynamo steel.

In the early years of magnetic separation in the Galena district, the pyrite was given what is called a sweet roast. The combination of zinc and pyrite was roasted anywhere from two to four hours at a bright red temperature. Such a roast made the pyrite very magnetic and ordinary medium intensity separators and even low intensity separators qualified for the separation. This heavy roast, however, resulted in the loss of the sulphur and it was soon discovered that by subjecting the mixture to a lighter skin roast, merely coating the outside surface with a magnetic iron oxide, that a high intensity separator would produce the desired results. This combination consequently resulted in the saving of the sulphur because very little of it was lost and the skin roasted pyrite was delivered to the sulphuric acid plant and practically all of the sulphur was recovered.

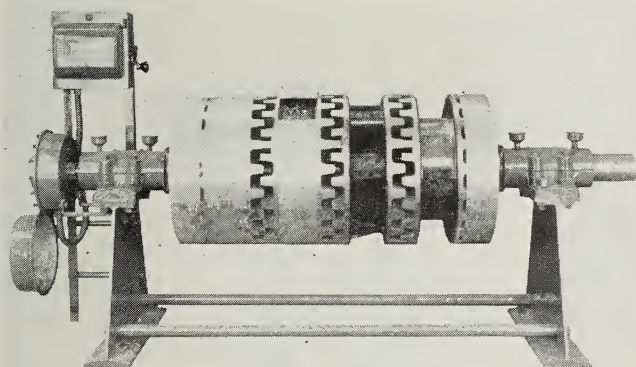


FIGURE 15.—The new air-cooled magnetic pulley has longitudinal and radial air circulating ducts. The surfaces are corrugated and promote a maximum amount of circulating surface. Tests have proved that, with this new design, an increase of strength up to 20 per cent is obtained. The use of bronze spacer rings is further assurance of the highest possible magnetic intensity.

At first high intensity separators had limited capacities as compared to the lower intensity type, but developments in the high intensity separator design has brought about the so-called super high intensity induction type separator, which involves the application of highly magnetized laminated rolls through induction from powerfully energized primary magnetic poles.

Illinois' greatest non-metallic mineral, of course, is coal. When mining much tramp iron finds its way into that coal. Even under ground, coal cutting knives, drill points, chains, railroad spikes, and other railroad iron, tools, etc., are hoisted to the surface with the coal. After the coal leaves the tipples more iron finds its way into it. Bolts, nuts and rivets become detached from the steel railroad cars and where whole carloads of coal are dumped by car dumping equipment, even brake shoes, handwheels and coupling pins fall with the coal.

The wide use of pulverized and stoker coal makes necessary the extraction of that miscellaneous tramp iron from it. Crushers must be protected from it, the pulverizers produce a highly explosive mixture which, when ignited through a spark, causes disastrous results, and even loss of lives.

It is a matter of record that some large consumers of coal recover enough iron to make the sale of it profitable. With handwheels, coupling pins and coal cutting knives worth considerably more than scrap, it has been found to be quite profitable to sort these parts from each other and sell them back to the original owner.

In several cases where coal yards were thoroughly cleaned up for repairs or for other reasons, so much iron had accumulated at the bottom of the coal piles that the crushers and pulverizers would have been fed a very high proportion of tramp iron if the magnetic separator had not been interposed between the coal pile and that machinery.

Illinois coal particularly has a high sulphur content. That sulphur exists in the form of iron pyrite. When taking into account the amount of unburned carbon falling through stoker grates, this type of firing at best is most uneconomical. Ordinary stoker cinders may contain as high as 40% unburned carbon. The balance of those cinders is roasted pyrite and ash. A simple screening process will eliminate the ash and you then have a combination of roasted pyrite, which is magnetic, and unburned carbon. The process of separation is almost identical to that encountered in the zinc district. The separator readily removes the roasted pyrite, not useable, however, for sulphuric acid, because it has been sweet roasted, and the unburnt carbon is easily recovered. That carbon, of course, does not have the B.t.u. value that the original coal had, because the hydrocarbon gases have been burned out.

This process of reclaiming unburned carbon from cinders is extensively used in Germany. Much work has been done on the process in this country, but at this moment it is not considered practical or economical, because coal is still so cheap that it really amounts to spending one dollar to save another.

Another problem involving the reclamation of the iron from powdered fuel fly-ash has been given some thought and study. The idea is far fetched and will probably never be commercial. The iron pyrite, where powdered coal is used, had been ground up finely and when burning this powdered coal the sulphur is thoroughly burned off. Flyash is a mixture of fine particles of iron and ash. The two are easily separated, but, as stated, the recovered iron costs more than it is worth.

The next largest non-metallic mineral in Illinois is silica. The Ottawa sands are world famous. Most of this silica, existing as St. Peter sandstone, is found in Kendall, LaSalle and Ogle counties. When these deposits were formed very little native iron ore found its way there. To be sure there is considerable animal and vegetable matter associated with this silica, but by

washing, these two are very readily eliminated. Further, much of the small amount of iron encountered exists in the form of oxides or rust. That, too, is quite easily washed off in part, but native magnetite and fine iron of abrasion is extracted by magnetic separators.

Without thorough washing and magnetic separation the average so-called Ottawa sand never ran over 0.04 per cent Fe_2O_3 . Washing and separation easily brings that iron content down to 0.025 per cent Fe_2O_3 and much of the sand, when thoroughly processed, will run as low as 0.014 per cent Fe_2O_3 .

In many parts much more money is spent to produce silica containing 0.06 per cent Fe_2O_3 . As stated, the Ottawa sand is world famous because of its low iron content, its fine structure and its proper alumina content, and other good qualities; and Ottawa could very nicely get along and compete with other sands by merely washing and drying, but in order to excel all other sands offered they do separate magnetically with both medium and high

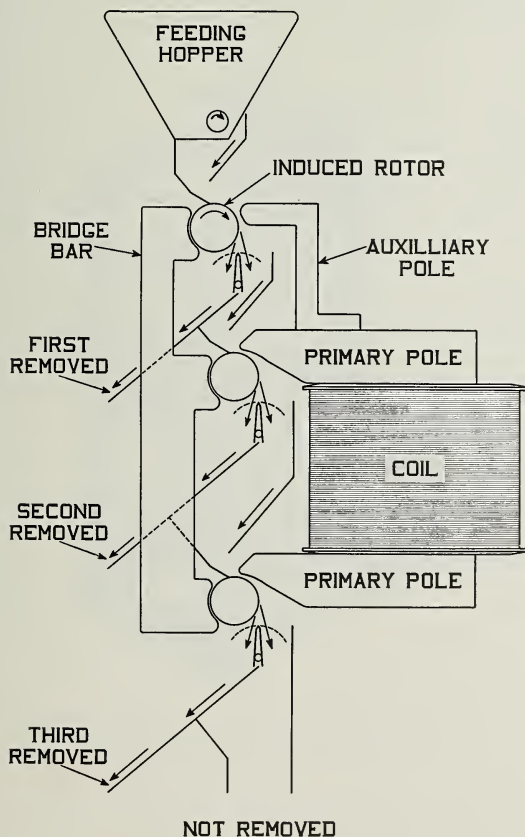


FIGURE 16.—Diagram illustrating the principle of the high intensity magnetic separator.

intensity separators and that brings about the willingness of the discriminating user of sand to pay a premium for the Ottawa sand. That sand is delivered as far east as the Eastern Seaboard, to upper New York and to the southeastern states. Other sand producers who can not produce such high quality have their shipping areas rather limited and they must be content also with a lower price for their commodity.

In Illinois we find clays also. Most of these are suitable for brick making, some for refractories. Magnetic separators find their widest application when used in the process of refining refractory clays. When these clays are weathered the pyrite associated with them becomes feebly magnetic and can be extracted with a high intensity separator. In the reclamation of crucibles, etc., when they are broken up (the resultant product is called grog) the iron which primarily existed as pyrite has been changed to the magnetic oxide and it is readily extractable magnetically. When using grog for producing new crucibles a considerable amount of new clay of course is added to bring about the desired plasticity.

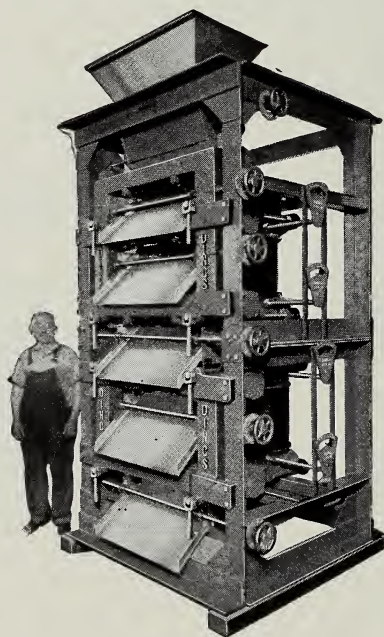


FIGURE 17.—A 30-inch five-roll type of magnetic separator used for concentrating ilmenite.

Where iron in any form exists in clay and where the surface is exposed to the elements, oxidation soon takes place with resultant pits, holes and discoloration. In refractory clays, when iron is present, the life of the crucible is shortened because of the difference in the coefficient of expansion

between the iron and the clay. Heat expands the iron and cracks the crucible; or excessive contraction of the iron produces leaky crucibles.

In Illinois there are a considerable number of potteries and glass plants and many of the raw materials used in these plants are separated magnetically. In common with both of these industries we find such products as borax, feldspar, dolomite and bauxite, all separated magnetically to remove the very small amount of iron present. Iron will discolor the product and produce defects on porcelain and china. Many dark specks, pimples and blisters are attributable to iron. Glazes and slip are run through wet type separators to remove this contamination.

In the glass industry, in addition to insuring against iron-contaminated ingredients in the batch, all cullet is separated to remove wires, bottle caps, abrasion iron from machinery and miscellaneous tramp iron. In the wire glass industry trimmings from the wire glass are crushed and separated. Such a reclamation would be utterly impossible if the wires were not removed from the glass before it was remelted.

The foregoing discussion outlines briefly some of the problems encountered in Illinois, but there are many materials susceptible to magnetic separation and to which magnetic separation has not yet been applied. The last five years have seen a considerable improvement in the design and application of magnetic separators and research work in the field is being carried on extensively.

Figure 16 illustrates the principle of the high intensity type of magnetic separator. The machine consists of a large primary magnet with pole pieces properly designed so as to induce a maximum amount of flux on to the laminated roll which is interposed between the primary pole of the magnet and the bridge bar. A minimum of clearance is allowed between the primary pole and the induced roll—just enough to allow the material to pass. The clearance between the bridge bar and the roll is just large enough to allow the roll to revolve freely.

The material is fed at the top of the machine by means of a specially designed feeder for the type of the material to be handled, and passes on to the first induced rotor or laminated roll. The first roll generally is an auxiliary roll designed to remove the very highly magnetic material. The magnetic material is removed at this point, but the nonmagnetic material passes to a second roll where the operation is repeated. Here again the magnetic material is removed and the nonmagnetic material passes to a third roll for a final separation. In practice any number of rolls can be used, and machines have been built with as many as nine induced rolls. Adjustable splitters or dividers are provided beneath each roll to regulate the amount of material removed as magnetic.

The high intensity type of magnetic separator developed by our company is the most efficient commercial machine manufactured today and separations heretofore considered impossible have been accomplished on this machine.

Typical applications are the purification of bauxite, reducing the iron content of chemical ore to a point required by the manufacturers of alum; reduction of iron content of silica sand used in the manufacture of glass; reduction of iron content in nepheline syenite, feldspar, borax and similar materials. In addition, this machine is used for concentrating tungsten, ilmenite, monozite, zircon, and similar feebly magnetic materials.

A laboratory is maintained by our company where complete magnetic analyses can be made on materials which may lend themselves to magnetic treatment. Many of the leading industries have had their problems solved in this laboratory.

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